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Evaluation of Concurrent Peak Responses

Prepared by P. C. Wang, J. Curreri, M. Shooman, Y. K. Wang,
A. J. Philippacopoulos, M. Reich, M. Subudhi

Brookhaven National Laboratory

Prepared for
U.S. Nuclear Regulatory
Commission

NUREG/CR-2685

EVALUATION OF CONCURRENT PEAK RESPONSES

MAY 1982

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P. C. Wang, J. Curreri, M. Shooman, Y. K. Wang,
A. J. Philippacopoulos, M. Reich, M. Subudhi

Brookhaven National Laboratory
Upton, NY 11973

Prepared for
Division of Engineering
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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Abstract

This report deals with the problem of combining two or more concurrent responses which were induced by dynamic loads acting on nuclear power plant structures. Specifically, the acceptability of using the SRSS (square root of the sum of the squares) value of peak values as the combined response is investigated. Emphasis is placed on the establishment of a simplified criterion that is convenient and relatively easy to use by design engineers.

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Table of Contents

	Page
List of Figures	iv
List of Tables	v
Executive Summary	1
Summary of Section 1 - Introduction	1
Summary of Section 2 - Proposed BNL Criteria	4
Summary of Section 3 - Combination of Two Earthquakes and Their Responses	5
Summary of Section 4 - Verification of Modified Kennedy-Newmark Criterion	5
Summary of Section 5 - Conclusions	5
1.0 Introduction	6
1.1 Probabilistic Model	6
1.2 Points of Agreement	9
1.3 Areas for Investigation	9
2.0 Proposed BNL Criteria	11
2.1 The Deviation Ratio (σ/R_{max})	11
2.2 Modification of the Deviation Ratio by Weighting Factors	13
2.3 Modified Threshold Deviation Ratio, σ^*/R_{av}	23
2.3.1 Calculating the Modified Deviation Ratio	25
2.3.2 Criterion for Mixed Signals	35
3.0 Combination of Two Earthquakes and Their Responses	45
3.1 Single-Degree-Of-Freedom System	45
3.2 Multi-Degree-Of-Freedom Systems	46
3.3 Conclusions Regarding the Combination of Earthquake Type Loads and Responses	46
4.0 Verification of Modified Kennedy-Newmark Criterion 1	89
5.0 Conclusions	124
References	126
Appendix A	A-1
Appendix B	B-1

BEST DOCUMENT AVAILABLE

List of Figures

Figure		Page
A	Modification Based on (Mark II Piping)	2
B	Modified Statistical Criterion	3
1	CDF for Combination of Response Histories	7
2	Nonexceedence Probability (NEP) Related to Δ/R_{max}	12
3	Modification Based on (Mark II Piping)	21
4	Modification Based on (Mark II Piping)	22
5	Assumed Triangular Waveshape for Evaluating B_j	28
6a	Use of Modified Threshold Criterion for NEP of SRSS	31
6b	Use of Original BNL Criterion for NEP for SRSS	32
7a	Combination of Responses - Different Durations	33
7b	Combination of Responses - Same Duration	34
8	Concurrent Signals With at Least One Common Point in Time	37
9	Modified Statistical Criterion	39
10	Example of Signals to be Combined	41
11	Earthquake on S.D.O.F. Systems	85
12	Earthquake on S.D.O.F. Systems	86
13	Earthquake on M.D.O.F. Systems	87
14	Earthquake on M.D.O.F. Systems	88

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List of Tables

Table		Page
1	Summary of Responses (Mark III) Piping	17
2	Threshold Values a_1/a_2 for Various Peak Signal Ratios	27
2a	Calculation of Deviation σ^* for Sigals in Figure 10	43
3	Earthquake Combination (15 sec duration)	48
4	Earthquake Combination (15 sec duration)	53
5	Earthquake Combination (15 sec duration)	58
6A	Frequencies	63
6B	Participation Factors	64
7	Earthquake Combination (15 sec duration)	65
8	Earthquake Combination (15 sec duration)	70
9	Earthquake Combination (15 sec duration)	75
10	Earthquake Combination (15 sec duration)	80
11	R.P.V. and Internal Response	91
12	Combination of Moment A, B, C	94
13	Earthquake Combination (5 Hz)	97
14	Earthquake Combination (10 Hz)	101
15	Earthquake Combination (15 Hz)	105
16	7 Degrees of Freedom (X)	109
17	7 Degrees of Freedom (Z)	113
18	30 Degrees of Freedom (X)	117
19	30 Degrees of Freedom (Z)	121

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Executive Summary

This report deals with the problem of combining two or more concurrent responses which were induced by dynamic loads acting on nuclear power plant structures. Specifically, the acceptablity of using the SRSS (square root of the sum of the squares) value of peak values as the combined response is investigated. Emphasis is placed on the establishment of a simplified criterion that is convenient and relatively easy to use by design engineers.

The report is divided into five sections. A brief summary of these sections follows:

Summary of Section 1 - Introduction

1. The probabilistic model used in this report is represented by two concurrent response time-histories with a random time lag between individual initiating times. If the maximum absolute individual peaks are R_{1m} and R_{2m}, the pertinent problem is to find the acceptable value of the combined result.

2. Consensus among the investigators is that a CDF (cumulative density function) of the combined responses can be plotted based on the random distributions of the time lag. It can either be produced by the Monte Carlo method or by an analytical approach. The acceptable NEP (non-exceedance probability) of the combined result should be equal to or above 0.84.

3. When the loads are determined statistically at a conservative level the acceptable NEP may be lower.

4. The SRSS value $\left(\sqrt{R_{1m}^2 + R_{2m}^2}\right)$ can be used as the combined result if it satisfies items 2 or 3 above.

5. Since the Monte Carlo or analytical approach may be time consuming and thus become unattractive to designers, a simplified criterion would be advantagious.

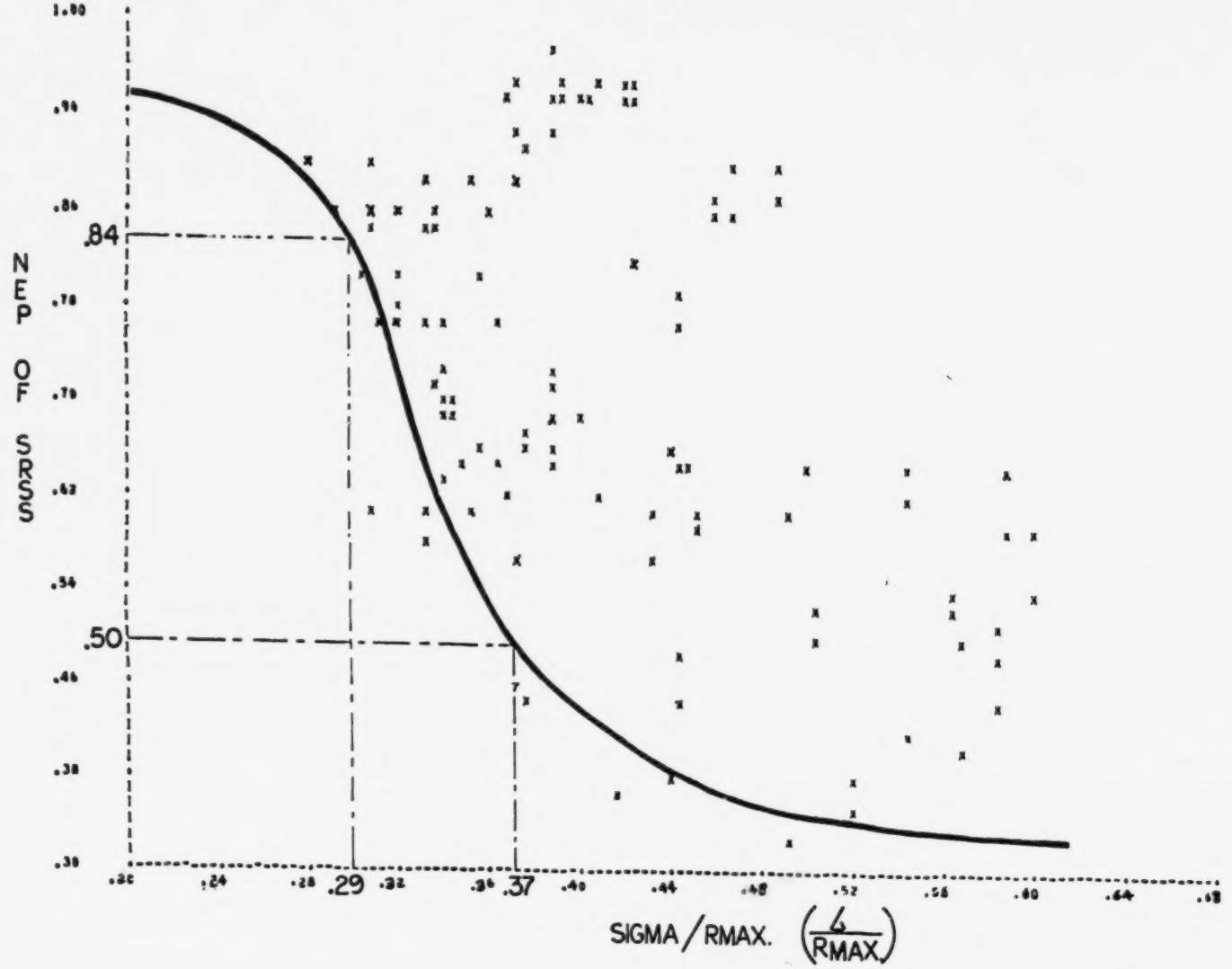

FIG. A MODIFICATION BASED ON $\frac{\sigma}{RMAX} = \frac{1}{\sqrt{2}}\sqrt{A_1\left(\frac{\sigma_1}{R_1m}\right)^2 + A_2\left(\frac{\sigma_2}{R_2m}\right)^2}$ WHERE $A_1 = \left(\frac{R_1m}{Rav.}\right)^2$, $A_2 = \left(\frac{R_2m}{Rav.}\right)^2$
(MARK II PIPING)

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$$\sigma^*/R_{av} = \sqrt{\frac{\left[B_1\left(\frac{\sigma_1^*}{R_{av}}\right)^2 + B_2\left(\frac{\sigma_2^*}{R_{av}}\right)^2\right]}{2}}$$

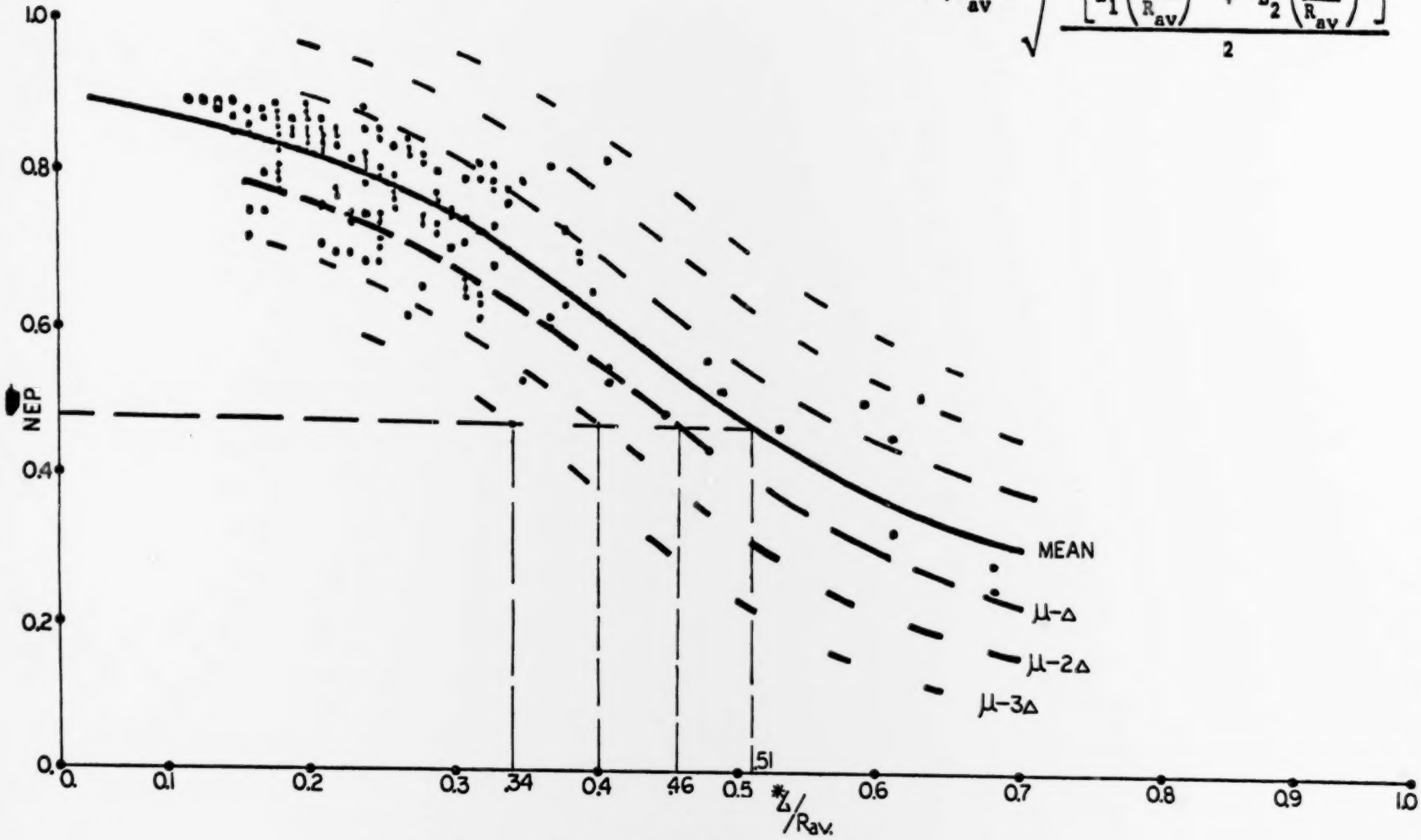

FIGURE B. MODIFIED STATISTICAL CRITERION

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Summary of Section 2 - Proposed BNL Criteria

1. The criterion originally proposed by BNL and described in (NUREG/CR 1333), based on the "deviation ratio σ/R_{max}" of individual response, where σ is the mean square root of the variance of the digitized response amplitudes and R_{max} is the absolute response peak is reviewed in detail for application to response combination application.

2. When two responses are different, the deviation ratio may be computed from the individual cases by applying weighting factors A_1 and A_2

$$\frac{\sigma}{R_{max}} = \frac{1}{\sqrt{2}} \sqrt{\left(\frac{\sigma_1}{R_{1m}}\right)^2 \times A_1 + \left(\frac{\sigma_2}{R_{2m}}\right)^2 \times A_2}$$

where

$$A_1 = \left[\frac{R_{1m}}{1/2\left(R_{1m} + R_{2m}\right)}\right]^{\alpha}, \quad A_2 = \left[\frac{R_{2m}}{1/2\left(R_{1m} + R_{2m}\right)}\right]^{\alpha}$$

$\alpha = 2$ or 1

3. Lower bound criterion for the deviation ratio based on the acceptable NEP of SRSS is plotted in Figure A for guidance in design application. For example:

Acceptable NEP = 0.84 then $\sigma/R_{max} \leq 0.29$

Acceptable NEP = 0.50 then $\sigma/R_{max} \leq 0.37$

4. The deviation σ used above reflects the statistical characteristic of the entire range of the amplitude of a particular response history. However, the effective range of the amplitude for evaluating the NEP of SRSS is limited to absolute values exceeding certain thresholds. For example, when two responses with equal peak values ($R_{1m} = R_{2m} = R_m$) are combined, the absolute response value of each of the responses less than the threshold of $0.414\ R_m$ has no effect on the NEP of SRSS. Only that portion of each of the signals

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greater than 0.414 of the peak affects the non-exceedance probability. A limited effort of investigation using this modified threshold deviation ratio as a criterion is carried out. The investigation indicates that the plot of NEP versus the modified deviation ratio is more closely bounded. The results are given in a statistical form where the mean and deviation beyond the mean are plotted. (See Figure B)

Summary of Section 3 - Combination of Two Earthquakes and Their Responses

1. Thirty-eight pairs of real earthquake time histories and their responses were combined to ascertain whether the SRSS rule can be used with safety for such types of dynamic responses.

2. Based on the comparisons of combined time histories at the load and at the response levels it is found that there is no consistency relating the combination results at the load and response levels. In order to find the response combinations, the characteristic of the load histories is not a sufficient indicator.

3. In general, if earthquake-like loads are defined conservatively at 84 percentile level so that NEP of 0.50 can be accepted, then the SRSS rule is applicable for response combination evaluation in the majority of cases.

Summary of Section 4 - Verification of Modified Kennedy-Newmark Criterion

1. The modified Kennedy-Newmark Criterion 1 uses the fractional duration above the thresholds 50% and 75% of the maximum as a criterion to determine the acceptance of SRSS Rule. It is an improvement over the original approach which used the number of peaks above the threshold.

2. When applied to 64 real responses (earthquake combined with SRV or Chug) less than half validated the criterion, a weak proof for its applicability.

3. For combining earthquakes with other earthquakes (i.e., without SRV or Chug, etc.), however, the modified Kennedy-Newmark Criterion stands up quite well.

Summary of Section 5 - Conclusions

The conclusions in Section 5 are summarized in the the above paragraphs.

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1.0 INTRODUCTION

Nuclear power plant structures, (piping systems and other components), are subjected to many dynamic loads such as earthquakes, loss-of-coolant accidents (LOCA), safety relief valve (SRV) actuations, etc. The designer must know how to combine the responses to these loads when more than one occurs concurrently. The basic problem is the determination of the resultant peak response. The time of occurrence and the amplitudes of these loads are probabilistic in nature. Even if these dynamic loads are postulated to occur concurrently, there still remains the uncertainty as to the phasing or time lag between the loads of the associated responses. The question of how to combine such responses and now to obtain the peak response has been investigated previously (1 to 6). This report presents a simplified criterion that is convenient and easy to use by those involved with nuclear safety and by the design engineer.

1.1 PROBABILISTIC MODEL

The problem can be modeled by assuming that the first response R_1 occurs at time zero, and second response R_2 begins seconds later (see Fig. 1a and 1b). The time lag τ is considered to be a random variable with an appropriate probability distribution. Since each response waveform, (response 1, response 2, or combined responses) can have either a positive or negative maximum, we define the maximum value as the larger of the absolute value of the positive or negative maximum, i.e.,

$$R_{max} = \text{Larger of} \left(|R_{max}|, |-R_{max}| \right) \qquad (1)$$

The solution to this probablistic model involves computing either analytically or via Monte Carlo methods (1,2,6), the cumulative distribution function (CDF) for the maximum of the combined response, R_{max} (see Fig. 1c and 1d) based on the random time lag τ. The CDF displays the probability that the value

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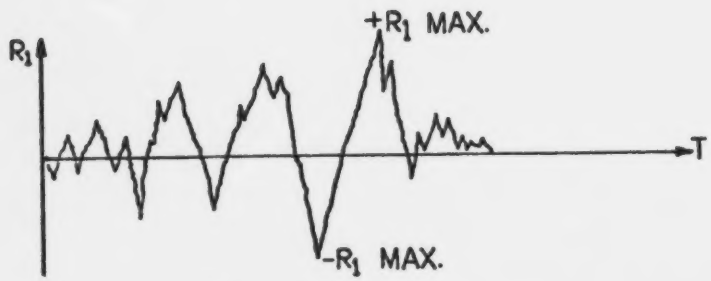
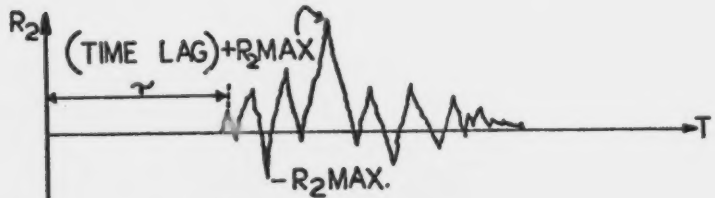
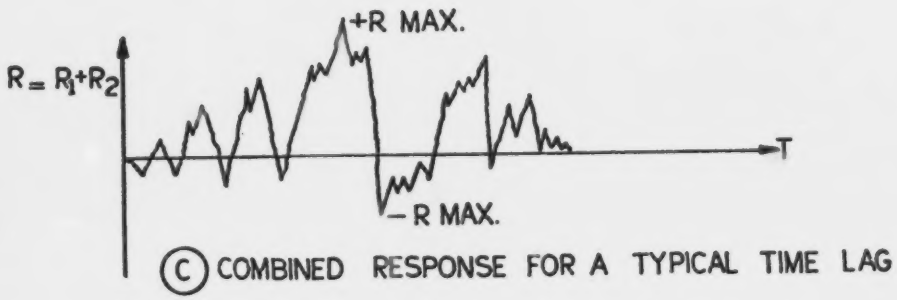


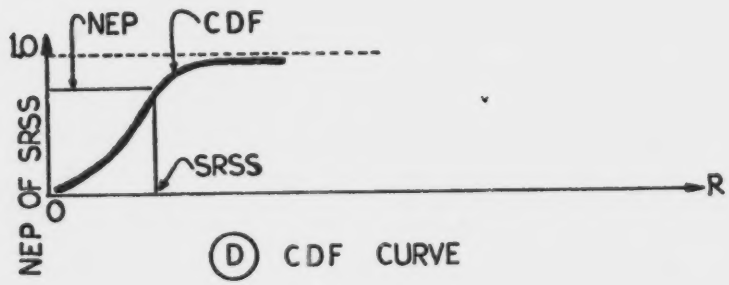
(A) RESPONSE 1



(B) RESPONSE 2



(C) COMBINED RESPONSE FOR A TYPICAL TIME LAG



(D) CDF CURVE

FIG. 1 CDF FOR COMBINATION OF RESPONSE HISTORIES

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of R_{max} is equal to or less than some value. Thus, the ordinate of the CDF curve is often called the non-exceedance probability, NEP.

A design measure suggested by some investigators is the square root of the sum of the squares (SRSS) which is defined as:

$$SRSS = \sqrt{(R_{1max})^2 + (R_{2max})^2} \tag{2}$$

Thus, a major focus of this study is the investigation of the NEP value which corresponds to the SRSS value, and under what conditions the use of the SRSS value as a design goal is acceptable. Of course one could always use the absolute sum of the maxima i.e.,

$$R_{abs} = |R_{1max}| + |R_{2max}|, \tag{3}$$

however, this may be too costly and conservative a criterion.

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1.2 POINTS OF AGREEMENT

In a previous study carried out by BNL (6) it was mentioned that a consensus has been reached among the cited investigators regarding several points. These are;

1) When the time-histories of two responses are available, a CDF can be plotted which represents the NEP versus the combined values of the peaks. The acceptable magnitude of the combined response to be used in design must have a non-exceedence probability of at least 0.84. Basically, if the NEP which corresponds to the SRSS value is greater than or equal to 0.84, then the use of the SRSS value as the combined result is acceptable.

2) In cases where the individual loads are known to be determined conservatively (e.g., with NEP $\geq$ 0.84 or 1.15 times the mean) considering the probabilistic nature of magnitudes, frequency content, etc., then a different acceptance criterion for SRSS may be used. Because of the built-in conservatism in the choice of loads, the NEP may be set at 0.50, (instead of 0.84), and in addition 1.2 times the SRSS must have an NEP $\geq$ 0.85.

3) The method of constructing the CDF curve should preferably be based on the absolute maximum as given in Equation 1 and discussed in (6).

4) Using SRSS for combining more than two responses appears to increase the NEP value.

1.3 AREAS FOR INVESTIGATION

Besides the concensus cited above, there are unresolved questions. Many of these are stated in the reports of the various investigators. The focus of this report is the investigation of these unresolved questions relating to the formulation of a simplified criterion.

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Section 2 of this report investigates the applicability of a simple criterion which has been proposed for determining when the SRSS value can be used as a design basis. The new technique is a modification of the previously proposed criterion, which is based on the deviation ratio (σ/R_{max}), (6).

Section 3 investigates the combination of two earthquake type loads and their responses. The objective is to identify whether the SRSS combination method can be applied uniformly to these types of loads. In addition, Section 3 attempts to resolve whether the SRSS method can be validated by examining either the load or the response characteristics.

Section 4 discusses the validity and limitations of the modified Kennedy-Newmark Criterion 1 (7). This Criterion is also designed to test when the SRSS rule is applicable.

Section 5 summarizes the results of this study, presents the conclusions and provides suggestions regarding some items that may require further verification.

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2.0 PROPOSED BNL CRITERIA

2.1 THE DEVIATION RATIO (σ/R_{max})

In the preceeding BNL work in this area (6), a simplified criterion was proposed to test cases where the SRSS rule for dynamic combinations is valid. It is based on a parameter called "The Deviation Ratio", defined as the ratio of the standard deviation to the peak value (σ/R_{max}) of the component response. If it is assumed that all responses have zero mean value then σ is the square root of the mean of the squares of the n digitized values of each response. The value of R_{max} is the absolute value of the maximum response (see Equation 1):

$$\frac{\sigma}{R_{max}} = \left(\sum_{i=1}^{n} R_i^2 / n \right)^{1/2} \Big/ R_{max} \qquad (4)$$

The NEP for the SRSS value and the deviation ratio were calculated for 30 pairs of artificial earthquakes shown in Tables 4.1 and 5.1 of (6) and are replotted here as Figure 2. Each pair of responses consists of two identical waveforms.

In Figure 2 the experimental points represent the NEP of the SRSS value determined by Monte Carlo methods along the ordinate and the deviation ratio (Equaiton 4) along the abscissa. Note that the data are closely clustered around the reverse "S-shaped" solid curve which is empirically fitted to the data.

To use such a curve, one must first decide what is the acceptable NEP for the SRSS value. If a NEP of 0.84 is chosen, then the acceptable deviation ratio is seen from the curve to be 0.29 or lower. On the

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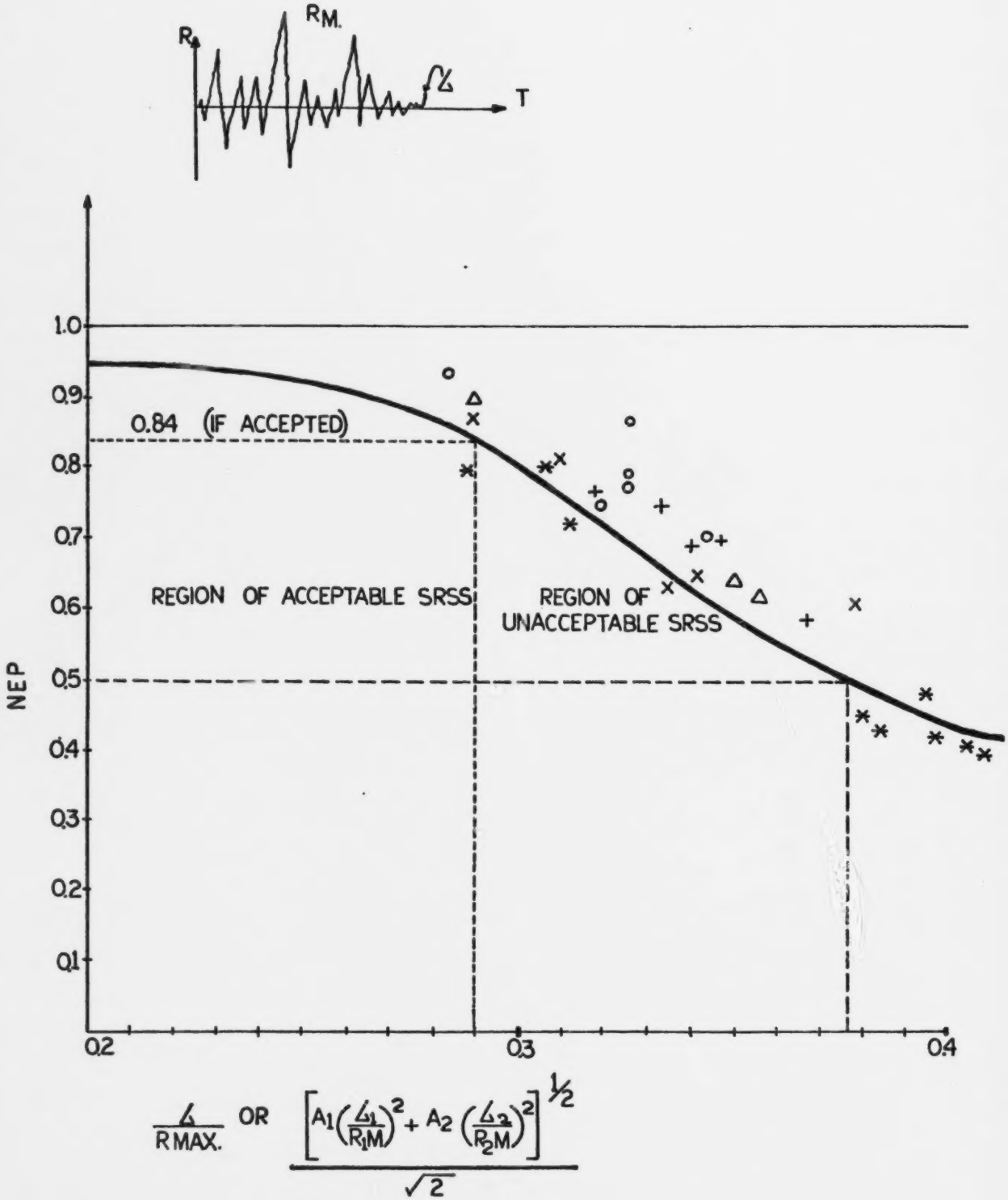

FIG. 2 NONEXCEDENCE PROBABILITY (NEP) RELATED TO $\frac{\Delta}{RMAX.}$

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other hand, if a NEP of 0.5 is chosen, then the acceptable deviation ratio must be 0.38 or lower. Since the computation of σ is easily done with a simple computer program or a desk calculator, when the time-history is available, this proposed criterion appears to be highly practical in the case of earthquake responses (assuming that the artificial responses closely resemble the real earthquakes).

However, when other responses with different characteristics are combined (such as earthquake combined with SRV) and a plot such as Figure 2 is prepared, the verification data points scatter a great deal around the empirical curve. In order to extend the usefulness of the criterion, a new modified criterion introduces a set of A_j weighting factors for each of the K responses.

$$\frac{\sigma}{R_{max}} = \left\{ \sum_{j=1}^{k} A_j \left(\frac{\sigma}{R_{max}} \right)_j^2 \right\}^{\frac{1}{2}} \qquad (5)$$

The determination of the A_j weighting factors is discussed in Section 2.2.

2.2 MODIFICATION OF THE DEVIATION RATIO BY WEIGHTING FACTORS

During the course of the investigation of the response combinations provided by General Electric (1), it was observed that significant discrepancies from the results of Figure 2 occurred when the ratio of the maximum values of two responses is great (say more than 6). In such cases, the NEP of SRSS predicted by the empirical curve shown in Figure 2 deviates a great deal from the actual Monte Carlo simulation result. Study of these results suggested that the addition of weighting factors to Equation 4 would improve the results. Thus, an investigation was made

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as to the effects of adding weighting factors A_1 and A_2 to the deviation ratio formula for two responses (C.F. Equation 5). The basis for choosing weighting factors A_1 and A_2 is given below.

The notation used to define the response waveforms is given in Figure 1. If R_1 and R_2 are Gaussian Stochastic processes with standard deviations σ_1 and σ_2, then the standard deviation of the combined response R is given by:

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2} \tag{6}$$

The largest value which the combined response can assume is:

$$R_{max} = R_{1max} + R_{2max} \tag{7}$$

We now consider two cases, the first with identical response types and the second with different response types:

Case 1 -- Two identical responses

When $R_1 = R_2$ and $\sigma_1 = \sigma_2$, we obtain from Equations 6 and 7:

$$\sigma = \sqrt{2\ \sigma_1} \tag{8}$$

$$R_{max} = 2\ R_{1max} \tag{9}$$

and the deviation ratio becomes:

$$\frac{\sigma}{R_{max}} = \frac{\sqrt{2\ \sigma_1}}{2\ R_{1max}} = \frac{1}{\sqrt{2}}\ \frac{\sigma_1}{R_{1max}} \tag{10}$$

In Figure 2, the abscissa represents the deviation ratio of the component response or σ_1/R_{1max}, (for identical responses). This means that the abscissa value is $\sqrt{2}\,\sigma/R_{max}$.

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Case 2 -- For two different responses

Again we assume two Gaussian Stochastic processes, $R_{1m} \neq R_{2m}$ (simplification of subscript m for max has been used) and $\sigma_1 \neq \sigma_2$. However, in this case Equation 6 and Equation 7 yield:

$$\frac{\sigma}{R_{max}} = \frac{\sqrt{\sigma_1^2 + \sigma_2^2}}{R_{1m} + R_{2m}} = \sqrt{\left(\frac{\sigma_1}{R_{1m}} \frac{R_{1m}}{R_{1m} + R_{2m}}\right)^2 + \left(\frac{\sigma_2}{R_{2m}} \frac{R_{2m}}{R_{1m} + R_{2m}}\right)^2} \qquad (11)$$

If we let $R_{av} = \frac{R_{1m} + R_{2m}}{2}$, then substitution in Equation 11 yields:

$$\frac{\sigma}{R_{max}} = \frac{1}{2}\sqrt{\left(\frac{\sigma_1}{R_{1m}}\right)^2 \cdot A_1 + \left(\frac{\sigma_2}{R_{2m}}\right)^2 \cdot A_2} \qquad (12)$$

where:

$$A_1 = \left(\frac{R_{1m}}{R_{av}}\right)^2 \quad \text{and} \quad A_2 = \left(\frac{R_{2m}}{R_{av}}\right)^2 \qquad (13)$$

If the same multiplication factor of $\sqrt{2}$ used for the identical responses is used here, Equation 12 becomes:

$$\frac{\sigma}{R_{max}} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{\sigma_1}{R_{1m}}\right)^2 \cdot A_1 + \left(\frac{\sigma_2}{R_{2m}}\right)^2 \cdot A_2} \qquad (14)$$

Note that if $R_1 = R_2$ and $\sigma_1 = \sigma_2$, then $R_{av} = R_1$, $A_1 = A_2 = 1$, and Equation 12 reduces to Equation 10. Since the choice of the A_1 and A_2 values in Equation 13 was based on intuition, another alternative definition of the weighting factors was also partially explored:

$$A_1 = \frac{R_{1m}}{R_{av}} \quad \text{and} \quad A_2 = \frac{R_{2m}}{R_{av}} \qquad (15)$$

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Response data from General Electric (Table 1 of this report and reference (6) were plotted relating the NEP of SRSS with the modified σ/R_{max} value as was done in Figure 2. The results based on 121 combinations are shown in Figure 3, where the weighting factors given in Equation 13 were used. In Figure 4, the results are replotted using the weighting factors given in Equation 15.

The data points in Figures 3 and 4 are still scattered, however, if a lower bound approach is adopted, empirical curves can be drawn as shown on the respective figures. When the same criterion as stated for the combination of identical responses (Figure 2) is used, at NEP of 0.84, the σ/R_{max} value is 0.30 and at NEP of 0.50, the σ/R_{max} value is 0.37. These values do not differ greatly from that shown in Figure 2. The raw data for Figures 3 and 4 are given in Table 1.

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TABLE I SUMMARY OF RESPONSES (MARK III) PIPING.

COMB. NO.	R_{1m}	R_{2m}	$R_{av.}$	Δ_1/R_{1m}	Δ_2/R_{2m}	MOD.1 $\Delta/R_{max.}$	MOD.2 $\Delta/R_{max.}$	NEP OF SRSS
1	30.70	207.00	118.85	.28	.33	.410	.324	.62
2	61.00	207.00	134.00	.28	.33	.372	.319	.57
3	30.70	236.00	133.35	.28	.35	.440	.343	.66
4	61.00	236.00	148.50	.28	.35	.402	.337	.69
5	31.60	195.00	113.30	.28	.34	.417	.332	.36
6	31.60	199.00	115.30	.28	.40	.491	.386	.35
7	62.90	195.00	128.95	.28	.34	.376	.326	.45
8	63.00	199.00	131.00	.28	.40	.440	.375	.38
9	327.00	991.00	659.00	.28	.33	.364	.318	.64
10	327.00	944.00	635.50	.28	.41	.443	.381	.65
11	5.10	1.50	3.30	.34	.36	.389	.345	.95
12	268.00	80.30	174.15	.34	.35	.387	.342	.92
13	10.20	1.53	5.87	.34	.36	.423	.343	.96
14	537.00	80.30	308.65	.34	.35	.423	.341	.95
15	5.10	4.33	4.72	.34	.38	.358	.359	.86
16	268.00	226.00	247.00	.34	.38	.358	.359	.86
17	10.20	4.30	7.25	.34	.38	.374	.352	.89
18	537.00	226.00	381.50	.34	.38	.374	.352	.92
19	166.00	16.60	91.30	.31	.48	.403	.329	.95
20	38700.00	3800.00	21250.00	.31	.50	.404	.331	.95
21	332.90	16.60	174.30	.31	.48	.419	.320	.96
22	77500.00	3800.00	40650.00	.31	.50	.419	.321	.95
23	166.90	47.00	106.50	.31	.43	.367	.340	.95
24	38700.00	10700.00	24700.00	.31	.47	.372	.351	.96
25	332.00	47.00	189.50	.31	.43	.391	.327	.96
26	77500.00	10700.00	44100.00	.31	.47	.394	.334	.95
27	48.20	18.90	33.55	.33	.43	.376	.361	.91
28	70500.00	7070.00	38785.00	.31	.37	.401	.316	.95
29	96.70	17.00	56.85	.33	.43	.407	.347	.96
30	141000.00	7070.00	74035.00	.31	.37	.418	.313	.95

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TABLE I (CONTINUE)

32	70500.00	21600.00	46050.00	.31	.46	.369	.351	.95
33	96.70	98.70	97.70	.33	.37	.351	.351	.88
34	141000.00	21600.00	81300.00	.31	.46	.390	.334	.99
35	2030.00	7190.00	4610.00	.29	.40	.450	.379	.60
36	2030.00	4200.00	3115.00	.29	.38	.386	.353	.64
37	39300.00	83700.00	61500.00	.28	.33	.342	.315	.68
38	39300.00	48200.00	43750.00	.28	.32	.306	.303	.86
39	29800.00	7820.00	18810.00	.42	.42	.486	.420	.87
40	29800.00	20300.00	25050.00	.42	.47	.444	.441	.79
41	4160.00	12600.00	8380.00	.29	.54	.583	.490	.51
42	4160.00	31400.00	17780.00	.29	.48	.601	.462	.54
43	61100.00	175000.00	118050.00	.28	.46	.493	.421	.60
44	4340.00	14100.00	9220.00	.26	.35	.388	.331	.73
45	222000.00	639000.00	430500.00	.28	.47	.504	.429	.50
46	29900.00	64300.00	47100.00	.28	.38	.388	.351	.71
47	2220.00	7660.00	4940.00	.28	.40	.448	.376	.64
48	2220.00	4570.00	3395.00	.29	.37	.377	.346	.66
49	28600.00	53800.00	41200.00	.29	.33	.336	.317	.71
50	28600.00	57500.00	43050.00	.29	.32	.332	.310	.85
51	126000.00	39500.00	82750.00	.42	.36	.468	.406	.86
52	126000.00	94000.00	110000.00	.42	.42	.424	.420	.82
53	22700.00	71100.00	46900.00	.29	.52	.566	.475	.40
54	22700.00	105000.00	63850.00	.29	.47	.586	.452	.64
55	134.00	2080.00	1107.00	.34	.39	.519	.387	.35
56	134.00	7670.00	3902.00	.34	.24	.334	.242	.60
57	16800.00	72500.00	44650.00	.33	.38	.445	.371	.44
58	16800.00	96000.00	56400.00	.33	.37	.451	.364	.58
59	88200.00	30400.00	59300.00	.42	.36	.461	.405	.86
60	88200.00	60600.00	74400.00	.42	.47	.444	.441	.79
61	24800.00	76600.00	50700.00	.29	.52	.565	.474	.54
62	24800.00	201000.00	112900.00	.29	.43	.543	.417	.64

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TABLE I. (CONTINUE)

63	17600.00	391000.00	204300.00	.29	.42	.569	.415	.500
64	6770.00	25000.00	15885.00	.29	.38	.432	.363	.600
65	4160.00	12600.00	8380.00	.29	.54	.583	.490	.510
66	24800.00	76600.00	50700.00	.29	.52	.565	.474	.540
67	2030.00	4200.00	3115.00	.29	.38	.386	.353	.640
68	18.00	13.50	15.75	.30	.38	.334	.337	.840
69	17.50	13.50	15.50	.27	.38	.318	.323	.860
70	52.00	52.00	52.00	.33	.33	.330	.330	.890
71	91.00	91.00	91.00	.32	.32	.320	.320	.800
72	118.00	118.00	118.00	.32	.32	.320	.320	.760
73	68.00	68.00	68.00	.28	.28	.280	.280	.900
74	96.00	96.00	96.00	.32	.32	.320	.320	.780
75	119.00	119.00	119.00	.32	.32	.320	.320	.780
76	52.00	29.00	40.50	.33	.38	.356	.349	.810
77	91.00	55.00	73.00	.33	.38	.354	.350	.660
78	118.00	72.00	95.00	.32	.40	.353	.352	.610
79	68.00	42.00	55.00	.28	.30	.294	.288	.860
80	96.00	61.00	78.50	.32	.37	.343	.340	.680
81	119.00	74.00	96.50	.32	.38	.347	.344	.650
82	68.00	41.00	54.50	.28	.35	.309	.308	.600
83	96.00	87.00	91.50	.32	.32	.320	.320	.760
84	119.00	99.00	109.00	.32	.36	.338	.339	.690
85	43.00	41.00	42.00	.38	.35	.366	.366	.620
86	86.00	86.00	86.00	.36	.32	.341	.341	.760
87	114.00	99.00	106.50	.33	.36	.344	.344	.700
88	68.00	45.00	56.50	.28	.36	.313	.314	.760
89	96.00	81.00	88.50	.32	.28	.305	.302	.810
90	119.00	98.00	108.50	.32	.29	.310	.307	.840
91	43.00	45.00	44.00	.38	.30	.341	.341	.700
92	2030.00	7190.00	4610.00	.29	.40	.450	.379	.590
93	2030.00	4200.00	3115.00	.29	.38	.386	.353	.660
94	39300.00	83700.00	61500.00	.28	.33	.342	.315	.730

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TABLE I. (CONTINUE)

95	39300.00	48200.00	43750.00	.28	.32	.306	.303	.900
96	29800.00	7820.00	10810.00	.42	.42	.486	.420	.900
97	29800.00	20300.00	25050.00	.42	.47	.444	.441	.790
98	4160.00	12600.00	8380.00	.29	.54	.583	.490	.480
99	4160.00	31400.00	17780.00	.29	.48	.601	.462	.590
100	61100.00	17500.00	39300.00	.28	.46	.340	.329	.630
101	4340.00	14100.00	9220.00	.26	.35	.388	.331	.680
102	2220.00	7660.00	4940.00	.29	.45	.502	.419	.640
103	2220.00	4570.00	3395.00	.29	.37	.377	.346	.670
104	26800.00	53800.00	40300.00	.29	.32	.331	.310	.760
105	26800.00	57500.00	42150.00	.29	.32	.335	.311	.860
106	126000.00	39500.00	82750.00	.42	.36	.468	.406	.900
107	126000.00	94000.00	110000.00	.42	.42	.424	.420	.820
108	22700.00	71100.00	46900.00	.29	.50	.545	.458	.420
109	22700.00	165000.00	93850.00	.29	.47	.586	.452	.590
110	222600.00	639000.00	430500.00	.28	.47	.504	.429	.520
111	29900.00	64300.00	47100.00	.28	.38	.388	.351	.660
112	134.00	2080.00	1107.00	.34	.39	.519	.387	.380
113	134.00	7670.00	3902.00	.34	.24	.334	.242	.580
114	16800.00	72500.00	44650.00	.33	.38	.445	.371	.490
115	16800.00	96000.00	56400.00	.33	.37	.451	.364	.610
116	88200.00	30400.00	59300.00	.42	.36	.461	.405	.870
117	88200.00	60600.00	74400.00	.42	.47	.444	.441	.770
118	24800.00	76600.00	50700.00	.29	.52	.565	.474	.530
119	24800.00	201000.00	112900.00	.29	.43	.543	.417	.620
120	17600.00	341000.00	204300.00	.29	.43	.582	.425	.440
121	6770.00	25000.00	15885.00	.29	.38	.432	.363	.570

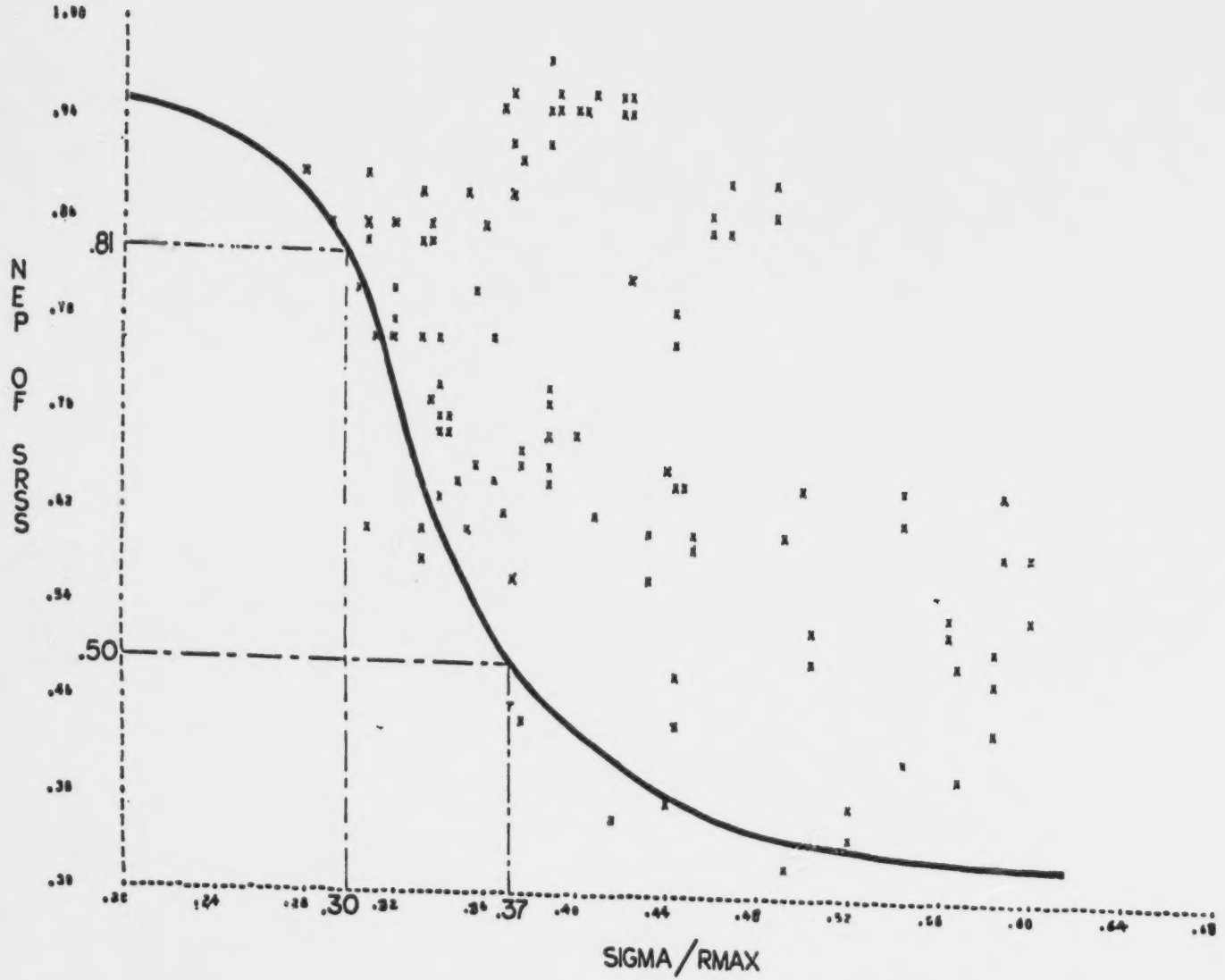

FIG. 3 MODIFICATION BASED ON (MARK II PIPING) $\frac{\Delta}{RMAX} = \frac{1}{\sqrt{2}}\sqrt{A_1\left(\frac{\Delta_1}{R_1 m}\right)^2 + A_2\left(\frac{\Delta_2}{R_2 m}\right)^2}$ WHERE $A_1 = \left(\frac{R_1 m}{R_{av.}}\right)^2$, $A_2 = \left(\frac{R_2 m}{R_{av.}}\right)^2$

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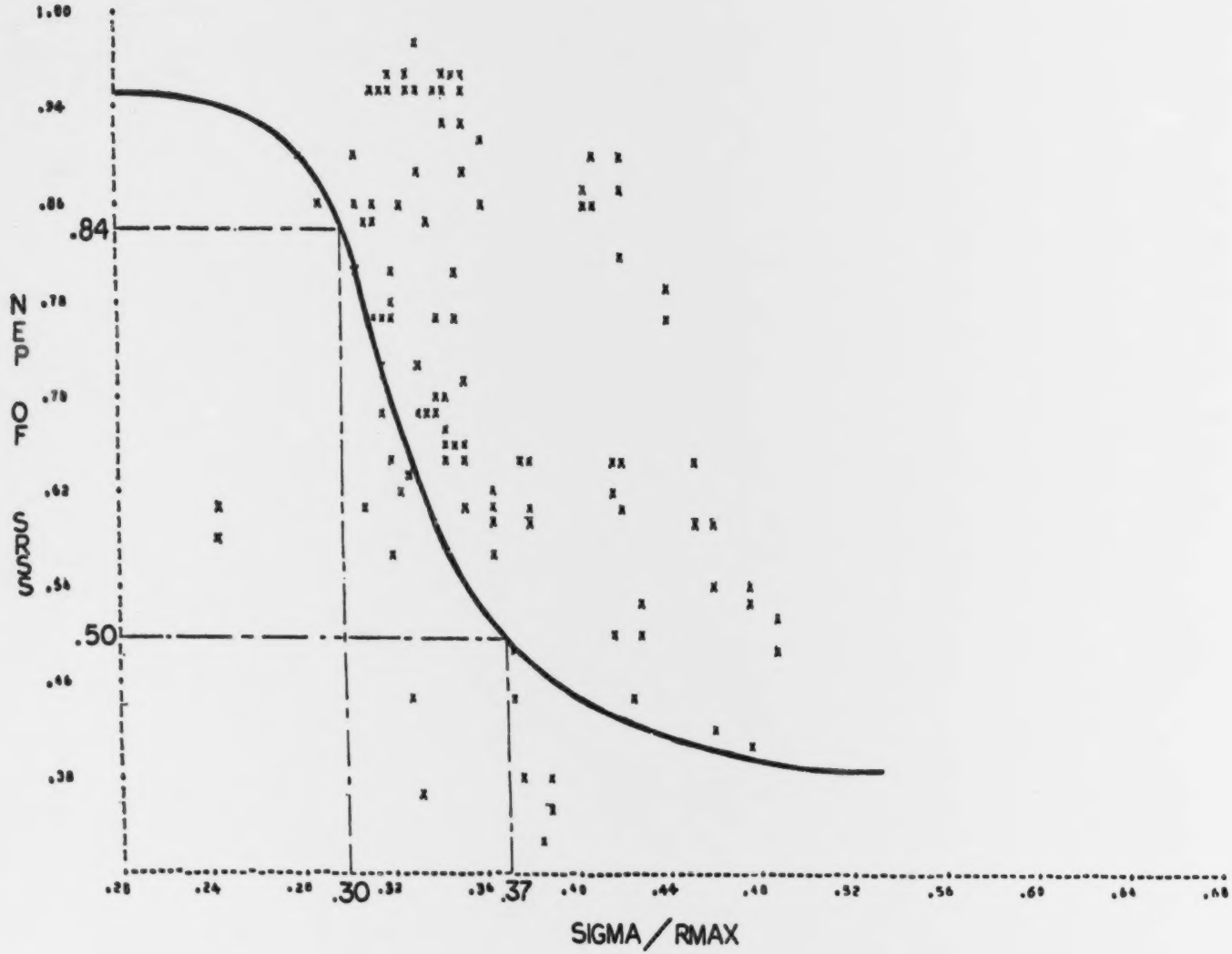

FIG. 4 MODIFICATION BASED ON (MARK II PIPING)

$$\frac{\sigma}{RMAX} = \frac{1}{\sqrt{2}}\sqrt{A_1\left(\frac{\sigma_1}{R_{1m}}\right)^2 + A_2\left(\frac{\sigma_2}{R_{2m}}\right)^2} \quad \text{WHERE} \quad A_1 = \frac{R_{1m}}{R_{av.}}, \; A_2 = \frac{R_{2m}}{R_{av.}}$$

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2.3 Modified Threshold Deviation Ratio, σ^*/R_{av}

The CDF curve has been used to identify the NEP of SRSS.† A simplified alternative to the CDF procedure has been described in Section 2.1. A study presented in Section 2.2 suggested that the use of weighting factors would improve the results. This current section discusses a modification of the preceding method of determining a σ/R_{max} value. The modified value is designated σ^*/R_{av} and is called the threshold deviation ratio, where R_{av} is the average of the maximum responses R_{1m} and R_{2m}.

The results of Section 2.2 were plotted in Figure 3 where a lower bound curve was established. The lower bound was intended to define the border line between an acceptable and non-acceptable use of SRSS in combining responses. Figure 4 has results similar to those of Figure 3 but introduces a modification in the definition of the abscissa. For this case, the weighting factors are different from those in Figure 3.

Further modifications are developed in this present section. These changes are intended to reduce the scatter of the data that is plotted. The aim is to obtain a relationship between the NEP and the σ^*/R_{av} that is more tightly bounded. If this is achieved, the data should therefore more closely define the relationship between the abscissa and the ordinate. With less scatter in the plot, statistics could then be more appropriately used to display the data and to interpret the results. In addition, it would be more convenient to present the data on a mean value at any σ^*/R_{av} location with bounding curves spaced one standard deviation apart. The lower bound curve could then be defined at two or three standard deviations from the mean. This would give some understanding of the confidence level of the lower bound.

To do this, two separate effects will be examined. The first is related to the spread of the data across any NEP level. This means moving horizontally

†Subsequent use of term NEP refers to NEP of SRSS.

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on the NEP vs. σ/R curve. Figures 3 and 4 show that the same NEP value could be obtained from different σ/R values. The second effect examines the spread of the data at any σ/R value. The curves of Figures 3 and 4 show that different ordinates are obtained for the same abscissa. The first effect is discussed in Section 2.3.1 and the modified procedure for reducing the variation in the data due to the second effect is presented in Section 2.3.2.

Some of the scatter of the data points is due to the randomness of the response signals. Any simple single measure that defines a property of the response could not completely capture the random nature of the signal. Responses are too complex to be so easily cataloged. Signals with the same σ/R property could have entirely different distributions of peak values, and so give different NEP values. Conversely, responses with different σ/R properties could result in the same NEP value. To reduce the scatter, more would have to be known about the distribution of the peaks. This task appears to be beyond the scope of the current objective since a simplified criterion is sought.

However, not all of the information contained in a response is significant in affecting the NEP. Much of the amplitude could be arbitrarily changed without affecting the NEP at all, but it would change the σ/R value. This occurs for amplitudes below a particular threshold level. Because of this, a modification of the procedure for evaluating the σ/R value was suggested. Only those amplitudes which could affect both the NEP ordinate as well as the σ/R abscissa were to be used when computing σ^*/R_{av} in the modified procedure.

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2.3.1 Calculating the Modified Deviaiton Ratio

The level below which no contribution is made to the NEP of SRSS varies with amplitude ratio. For two responses with equal magnitude of the peak values, it has been shown in Reference 6, pg. G-28 that the portion of the signal below 0.414 of the peak value is of no consequence in affecting the NEP of SRSS. Only that portion of each of the signals greater than 0.414 of the peak affects the nonexceedance probability. The value of this threshold changes as the amplitude ratio between the two signals increases. As an example, when two responses differ greatly in peak values, the threshold fraction for one of the responses becomes less that 0.414 and thus a greater portion of the signals affects a deviation ratio than is related to the NEP. At the same time, the threshold fraction is increased for the larger response. Since the smaller amplitudes below the threshold can affect only the abscissa, but not the ordinate of the NEP versus σ/R_{max} plot, a modification is suggested for calculating the deviation value. The modification is intended to include in σ only those values of the signal that exceed the threshold level, above which both the NEP, as well as the σ/R_{max}, are affected. The modified value is designated σ^* and is calculated as

$$\sigma_j^* = \sqrt{\frac{\Sigma(R_i - r_j)^2}{n}} \quad \text{for } R_i - r_j > 0, \; \begin{matrix} i = 1, 2, 3 \ldots n \\ j = 1, 2 \end{matrix} \tag{16}$$

where the r_j are the threshold values. Figure 5 shows two signals to which these definitions will be applied.

Threshold fractions, a_j, are determined from the definition of SRSS.

$$SRSS = \sqrt{(R_{1m})^2 + (R_{2m})^2} \tag{17}$$

$$\frac{SRSS}{R_{1m}} = \sqrt{1 + \left(\frac{R_{2m}}{R_{1m}}\right)^2} \tag{18}$$

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We can find coefficients a_j such that

$$a_1 R_{1m} + R_{2m} = \text{SRSS} \tag{19}$$

and

$$R_{1m} + a_2 R_{2m} = \text{SRSS} \tag{20}$$

From these equations, the threshold fractions both are calculated to be 0.414 for equal amplitude signals. As R_{2m}/R_{1m} increases, the threshold of the smaller signal decreases while that for the larger signal increases. Table 2 shows the a_j threshold fractions for various signal ratios which were computed from Equations (19) and (20).

An examination of the table shows that when a large ratio exists between the amplitudes of the two signals, only a very small portion of the tips of the larger signal is a factor which affects the NEP. The remainder of the signal below this value cannot change the NEP of SRSS.

Previously, weighting factors A_i were introduced into the equation for evaluating σ/R_{max}, as shown in Equation 12. Similarly, new factors B_j will be used for evaluating σ^*/R_{av}. These factors are intended to consider the shorter duration of the peaks above the threshold level as compared with the duration of the signal below the threshold.

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TABLE 2

Threshold Values a_1/a_2 for Various Peak Signal Ratios

R_{2m}/R_{1m}	SRSS/R_{1m}	a_1/a_2
1	1.414	.414/.414
2	2.24	.24/.62
3	3.16	.16/.72
4	4.12	.12/.78
5	5.10	.10/.82
6	6.08	.08/.847
8	8.06	.06/.882
10	10.05	.05/.905

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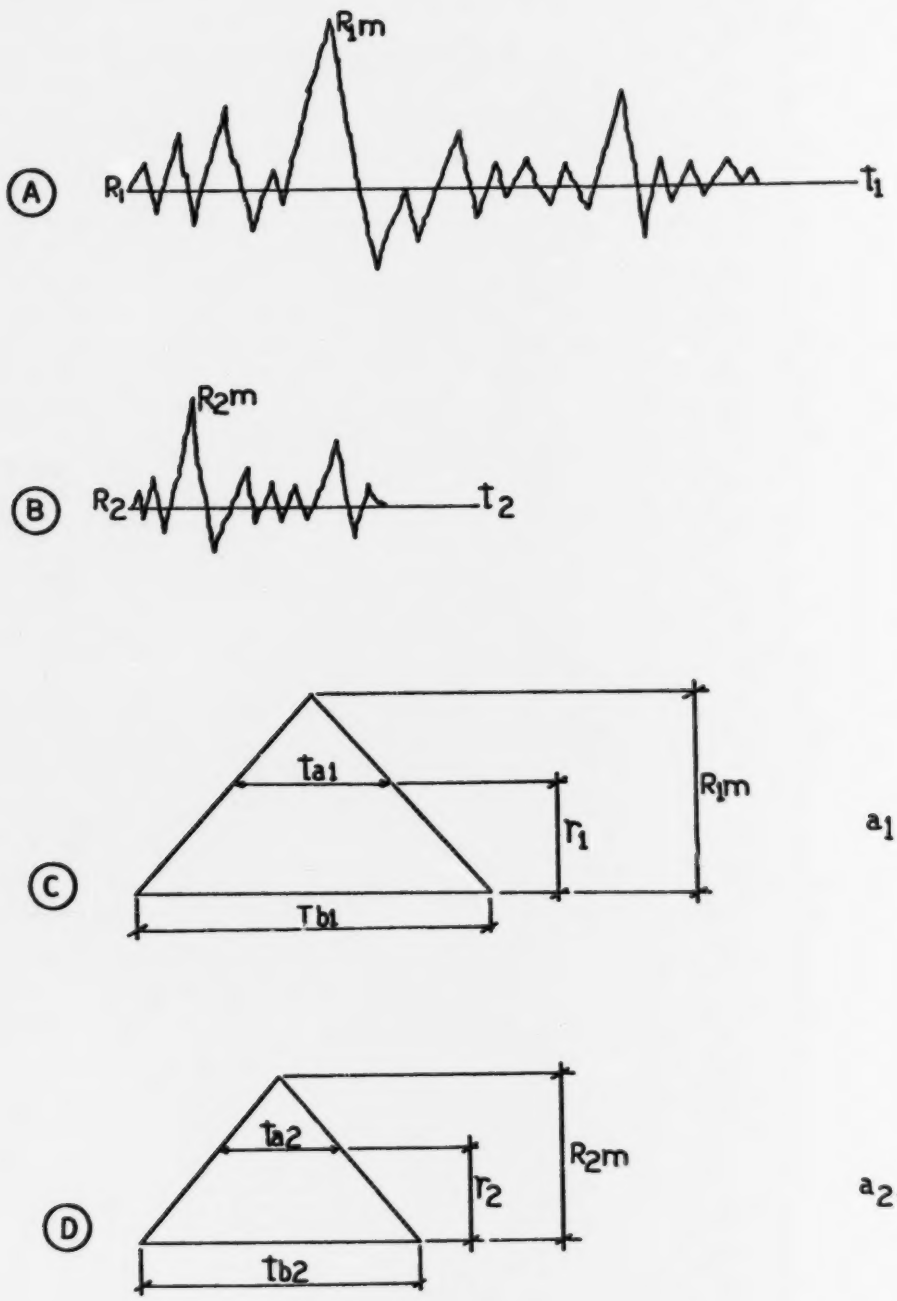

$$a_1 = \frac{r_1}{R_1m}$$

$$a_2 = \frac{r_2}{R_2m}$$

FIGURE 5

Assumed Triangular Waveshape for Evaluating B_j

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From Equation 4, the value of n is related to the total time interval of the signal. The magnitude of the weighting factors B_j will be obtained so that the relatively small amount of time that the signal is above the threshold level is considered. Figures 5(a) and 5(b) show two signals with the maximum peaks identified by R_{1m} and R_{2m} respectively. A triangular wave shape is assumed for simplicity. From Figure 5(c) and 5(d), we can express the following relations from similar triangles,

$$\frac{t_{a_1}}{t_{b_1}} = \frac{R_{1m} - r_1}{R_{1m}} = 1 - \frac{r_1}{R_{1m}} = 1-a_1 \tag{21}$$

$$\frac{t_{a_2}}{t_{b_2}} = \frac{R_{2m} - r_2}{R_{2m}} = 1 - \frac{r_2}{R_{2m}} = 1-a_2 \tag{22}$$

where the a_1 and a_2 are listed in Table 2.

The factors B_j are defined as

$$B_1 = \frac{1}{1 - a_1} \tag{23}$$

$$B_2 = \frac{1}{1 - a_2} \tag{24}$$

The overall proposed equation for evaluating the abscissa on the NEP of SRSS plot is

$$\frac{\sigma^*}{R_{av}} = \sqrt{\frac{B_1\left(\frac{\sigma_1^*}{R_{av}}\right)^2 + B_2\left(\frac{\sigma_2^*}{R_{av}}\right)^2}{2}} \tag{25}$$

The ratio σ^*/R_{av} is termed the Threshold Deviation Ratio.

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Only limited results have been obtained with the Threshold Deviation Ratio method. Figure 6a shows the results using the method on 35 G. E. cases (Table G-1 of Reference 6). Figure 6b shows the results using the original definition of σ/R_{max} for the same 35 cases. Some improvement is obtained in defining the relationship between NEP and the deviation ratio, as seen by comparing Figures 6a and 6b. Figure 7a shows the results for 60 G. E. cases (Tables G-2 to G-6 of Reference 6) for which the ratio of R_{2m}/R_{1m} is less than 20 and for which the duration ratios are greatly different for each response. The results show that the spread of the data is more contained as indicated by the dashed lines. Previous plots of the same cases showed a greater dispersion of the data (Figures 3 and 4).

The same procedure was applied to the combination of the responses of two randomly selected earthquakes. The responses of Section 3.0 were used to obtain a plot of the NEP of SRSS versus σ^*/R_{av}. For these cases, both responses were of the same duration. Figure 7b shows the data that was obtained. Again, the dashed lines shows that the data points are more contained both on the high σ^*/R_{av} side as well as on the low side when compared with the same cases by the previous method (Figures 8 and 9). It is therefore concluded that a tighter limit could be defined on the allowable σ/R_{av} ratio if the coefficients B_j are determined from the threshold values.

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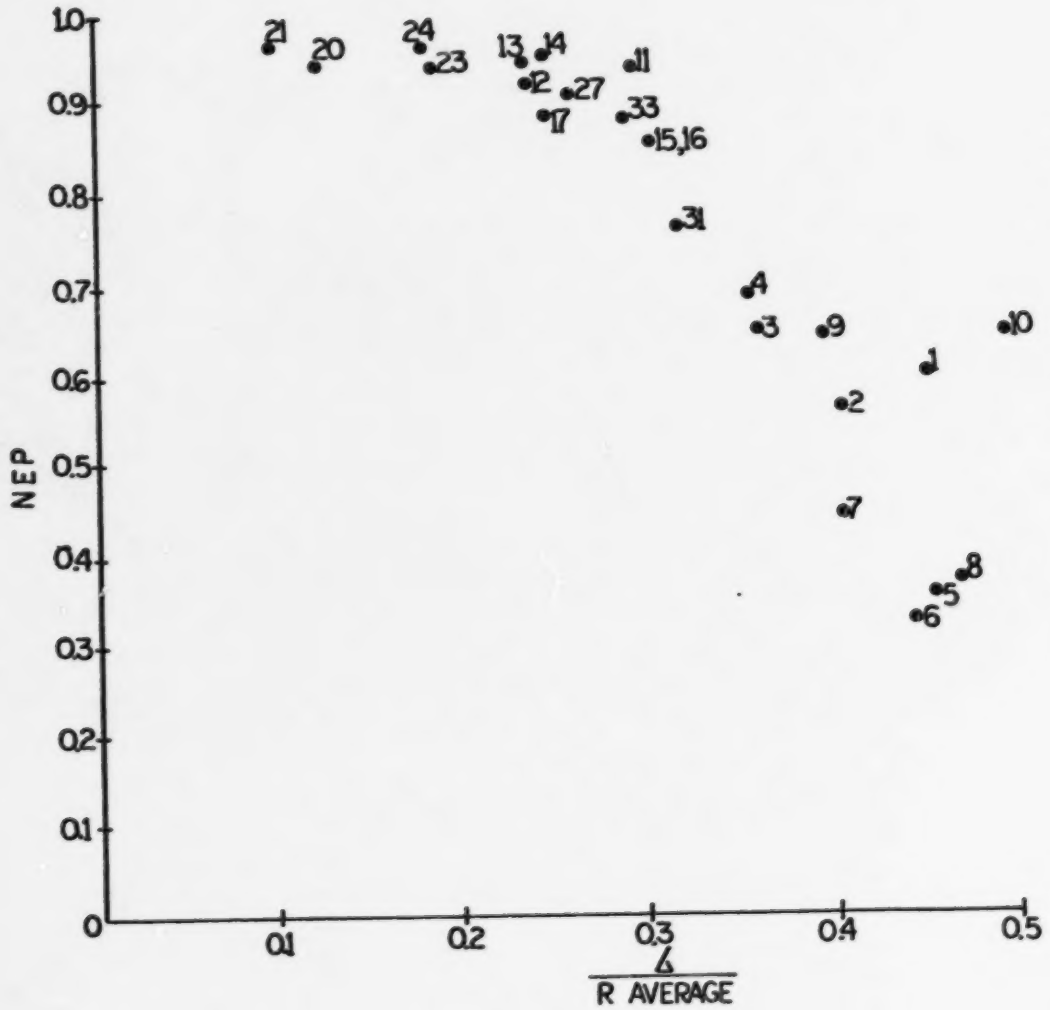

Use of Modified Threshold Criterion for NEP of SRSS

FIGURE 6a

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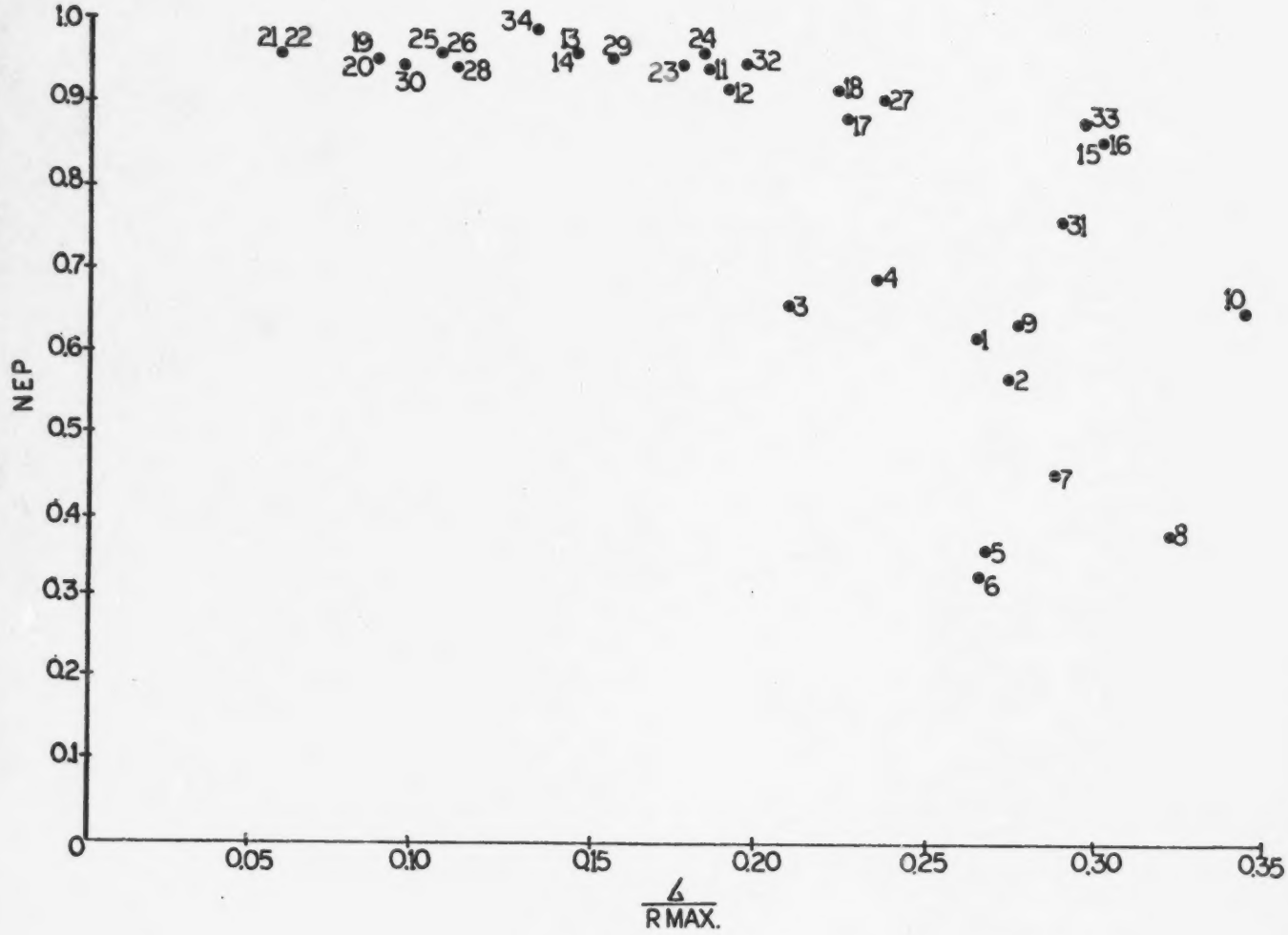
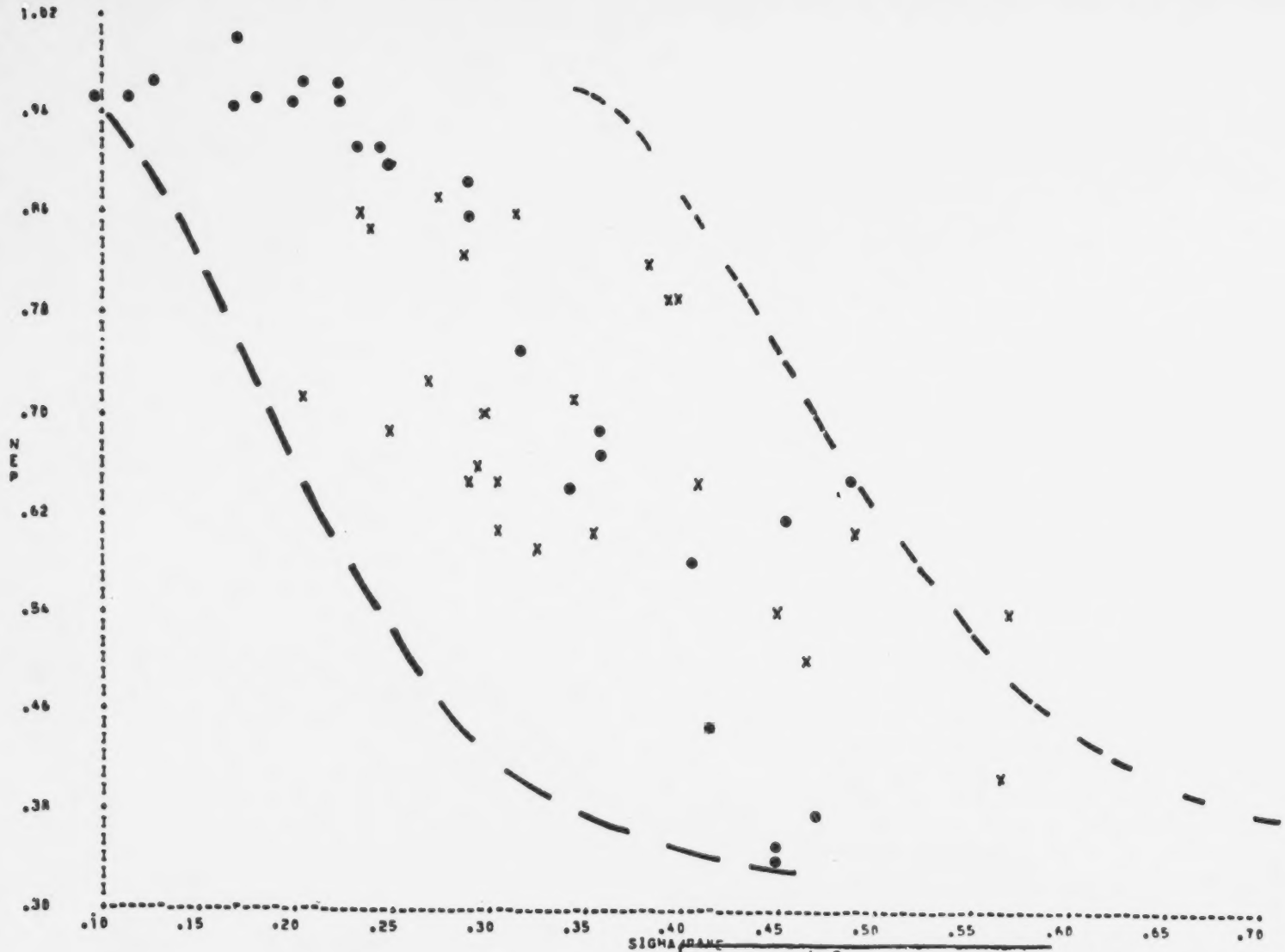


Use of Original BNL Criterion for NEP of SRSS

FIGURE 6b



$$B_1 = \frac{1}{1-a_1} \qquad B_2 = \frac{1}{1-a_2} \qquad \sigma^*/R_{av} = \sqrt{\frac{\left[B_1\left(\frac{\sigma_1^*}{R_{av}}\right)^2 + B_2\left(\frac{\sigma_2^*}{R_{av}}\right)^2\right]}{2}}$$

FIGURE 7a. Combination of Responses - Different Durations

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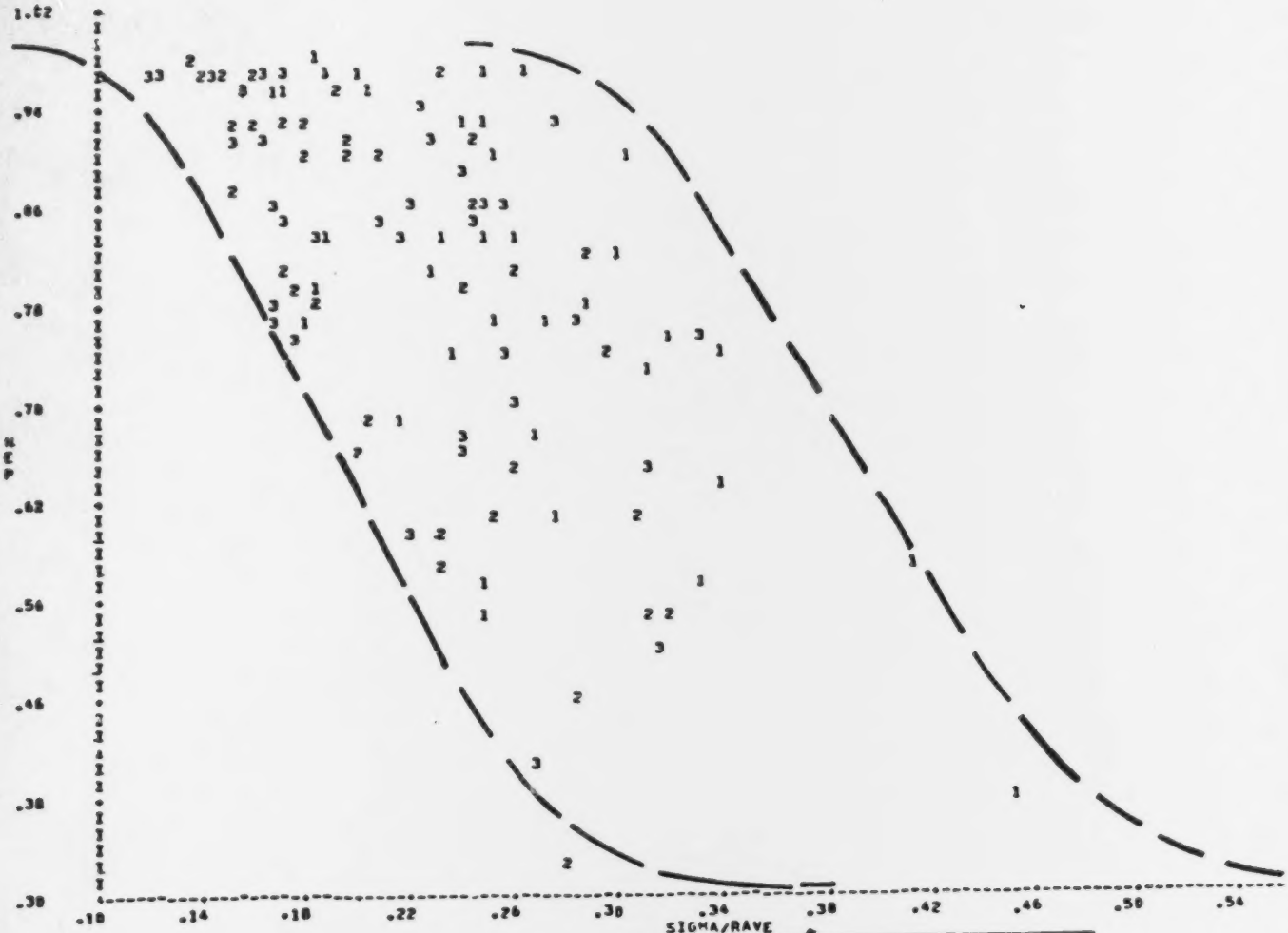

$$B_1 = \frac{1}{1-a_1}, B_2 = \frac{1}{1-a_2}$$

$$*\sigma/R_{av} = \sqrt{\frac{\left[B_1 \times \frac{*\sigma_1}{R_{av}}^2 + B_2 \times \frac{*\sigma_2}{R_{av}}\right]^2}{2}}$$

FIGURE 7b. Combination of Responses - Same Duration

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2.3.2 Criterion for Mixed Signals

Figures 7a and 7b plot the values of NEP vs. σ^*/R_{av} for two different classes of load combination problems. The first is for the combination of signals that have different durations. The second is for the combination of signals that have the same duration. These signals were obtained from the 35 G.E. cases that were studies and from the earthquake responses that were studied and are discussed in Section 3.0. If a more generically applicable curve is to be generated, however, the relationship between NEP and σ^*/R_{av} should reflect only the essential characteristics in the signals themselves. The relative duration of the signals should be considered in the procedure that evaluates the deviation ratio. The interpretation of the curve should inherently include the factors which affect the relationship between the non-exceedance probability and the deviation ratio. The interpretation should not be affected by the source of the signal or the signal types. Any two signals should have a characteristic value of deviation ratio that reflects the essence of the non-exceedance probability of SRSS when the signals are combined.

However, the procedure for evaluating and for demonstrating the use of the criterion has been to use existing curves from actual cases together with responses obtained from a particular structure due to particular earthquakes. The responses were assumed to be concurrent. This was defined to mean that the shorter signal could not preceed the longer one. Concurrence was interpreted to mean that the shorter duration signal could not start any sooner than the start of the longer one, but the shorter signal could start as late as the end of the longer one.

For two signals so defined, the possible overlap of some of the peaks is restricted. A large peak in the shorter signal that occurs after

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a large peak, or groups of peaks, in the longer one has no possibility of combining with these peaks. This type of situation is a result of the definition of concurrence. For such a case, the NEP could be affected simply by interchanging the second signal with the first. Of course, in this process, the value of σ^*/R_{av} remains unchanged. The NEP, however, would be changed, for the same σ^*/R_{av}, by the relative shifting in time of the occurrence of the peaks.

To try to develop a more generically applicapable criterion, the limits of the allowable time occurrences of each signal was redefined. Concurrence was taken to mean that the signals had at least one point in common. The second signal was taken to start over a time interval that extended beyond either end of the first signal. This is shown in Figure 8. This procedure insures that every peak of one signal has a uniform probability of combining with every peak in the other signal. However, the total time interval over which the probability is evaluated is increased, which raises the NEP when compared to the same cases computed by the original procedure.

The procedure shown in Figure 8 was implemented for the cases previously shown in Figure 7a and Figure 7b. A factor was introduced to account for the increase in the NEP value because of the different definition that was used in terms of concurrence. The results are shown in Figure 9. The plot shows the calculations of NEP vs. σ/R_{av} for all of the data that was readily available, including the G.E. cases as well as the cases of equal duration earthquakes that are discussed in Section 3.0. A total of 135 cases were plotted.

The spread of the data, plotted in Figure 9, is seen to be more closely bounded than any of the previous plots. Accordingly, a mean

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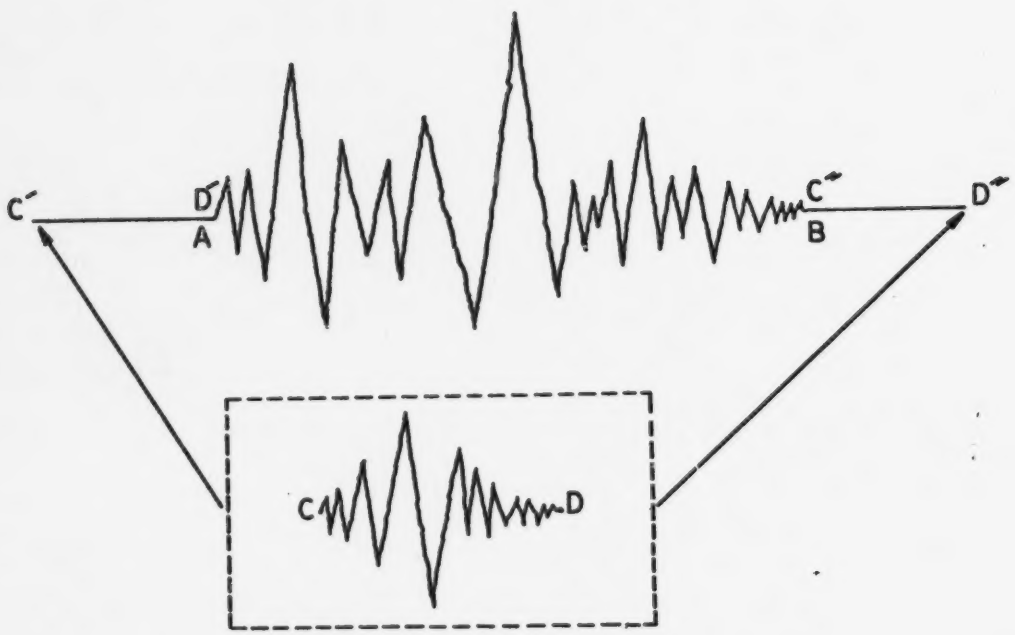

FIG. 8 CONCURRENT SIGNALS WITH AT LEAST ONE COMMON POINT IN TIME

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value and a standard deviation were determined at each interval. The mean values are shown by the heavy line in the figure. The dashed lined identify values that are one, two or three standard deviations from the mean.

The data in Figure 9 is plotted from 135 cases with different characteristics. It includes responses of three different one-degree-of-freedom system which were subjected to 38 pairs of earthquakes. It also includes the G.E. cases which are the SRV and LOCA responses which were combined with the earthquakes. The data points are for combination of responses arising from the different earthquakes as well as SRV and LOCA excitations. The results of these combinations are characterized and plotted in Figure 9 in terms of a mean curve relating σ^*/R_{av} vs. NEP together with the bounding curves which identify the locus of points at one, two and three standard deviations of the data away from the mean. All of the points in Figure 9 fall within the 3Δ level.

A criterion could be established by using a curve like the one in Figure 9. The procedure for applying the criterion follows the discussion associated with Figure 2. However, the new plot in Figure 9 now statistically defines the local distribution of the points that have been evaluated. A decision has to be made in terms which curve should be used to define the division between the acceptable and non-acceptable regions for using SRSS. At an NEP level of 0.5, the acceptable deviation range is seen to be less that either 0.51, 0.46, 0.40 or 0.34, depending on whether the mean or a 1Δ, 2Δ or 3Δ level below the mean is used respectively. On the other hand,

$$\sigma^*/R_{av} = \sqrt{\frac{\left[B_1\left(\frac{\sigma_1^*}{R_{av}}\right)^2 + B_2\left(\frac{\sigma_2^*}{R_{av}}\right)^2\right]}{2}}$$

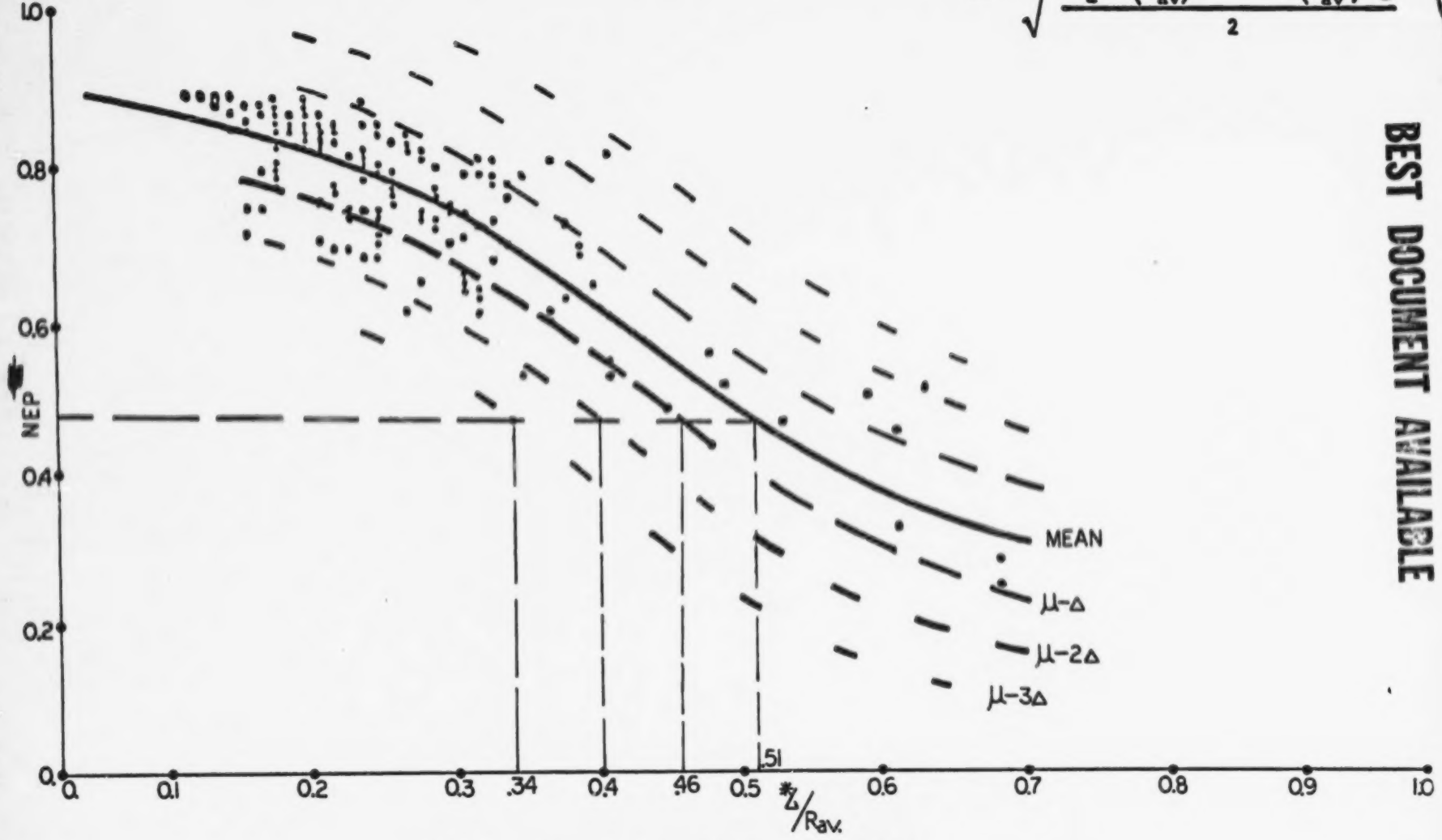

FIGURE 9. MODIFIED STATISTICAL CRITERION

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for an NEP of 0.84, only the mean curve is available for using SRSS and, for this case, a deviation of 0.2 or less is required. It is clear that this case inherently does not include enough assurance that the use of SRSS is satisfactory. For this reason, the curve would not be used to conservatively evaluate the non-exceedance probability of SRSS unless the responses were obtained from loads that were themselves conservatively defined at least at the 84% level. For this case, an NEP level of 50% may therefore be used and a conservative limitation on the deviation value would be $\sigma^*/R_{av} = 0.34$, which corresponds to a curve level in Figure 9 of the mean minus 3Δ.

An example will be used to show the details of the procedure that would be followed if a set of curves, such as Figure 9, were used as the criterion for determining the acceptability of SRSS as compared to the absolute sum method of combining signals.

Figure 10 shows two concurrent responses which are to be combined. The first response has a time duration of 10 seconds and the second occurs for 7 seconds. The numbers of peaks in both are sparce. The peak amplitude of the shorter duration signal is twice the amplitude of the first. R_{2m} occurs at t = 4.4 seconds and R_{1m} occurs at t = 3.6 seconds. The following six steps are carried out to evaluate the acceptability of SRSS.

1. From the curves, Figure 10, $\frac{R_{2m}}{R_{1m}} = 2.0$

2. From Table 2.0, $SRSS/R_{1m} = 2.24$, so that from the last column,

$$a_1 = 0.24 = r_1/R_{1m} \text{ (see Equation 21)}$$

and

$$a_2 = 0.62 = r_2/R_{2m} \text{ (see Equation 22)}$$

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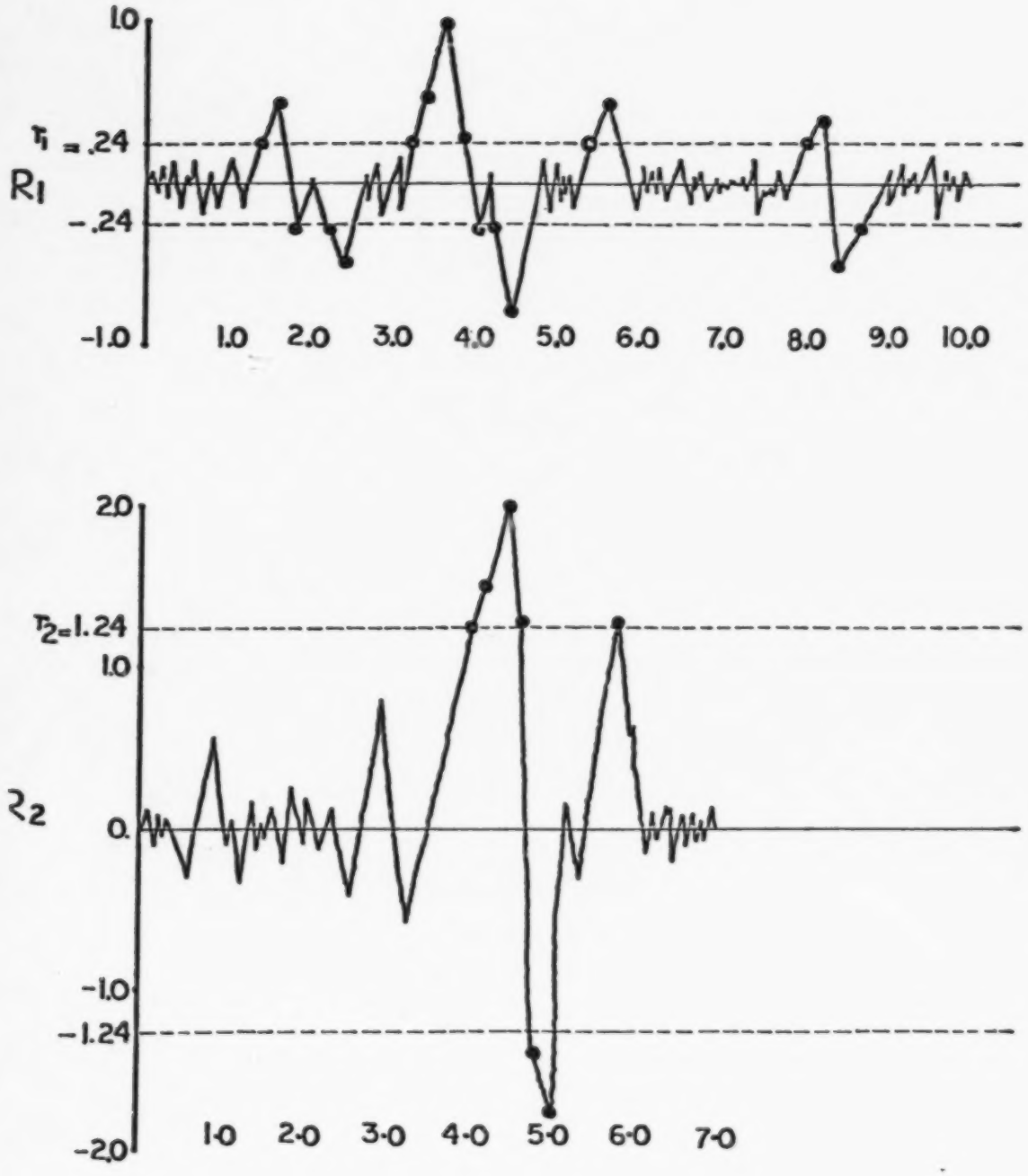

FIG.10 EXAMPLE OF SIGNALS TO BE COMBINED

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3. Use Equations 23 and 24 to calculate

$$B_1 = \frac{1}{1-a_1} = \frac{1}{1-0.24} = 1.316$$

$$B_2 = \frac{1}{1-a_2} = \frac{1}{1-0.62} = 2.632$$

4. Select a time increment of 0.2 seconds which gives 50 sampling points in 10 seconds for this example. List only those values of R_i that exceed the thresholds of r_1 and r_2. For R_1, the first time the signal crosses the threshold is at 1.4 seconds. The heavy dots in Figure 10 identify those amplitude values that exceed the threshold and are used in evaluating σ^*.

Table shows all of the values that are used from both curves. For this case only 18 values of R_1 are used and 7 values of R_2. The second column in Table 2a shows the value of $(R_i - r_i)$ and the third column gives $(R_i - r_i)^2$. σ^* is calculated from Equation 16, where n is 50 in each response, and is shown at the bottom of Table 2a.

5. Calculate $R_{av} = \frac{R_{1m} + R_{2m}}{2} = \frac{1.0 + 2.0}{2} = 1.5$

6. Calculate $\sigma^*/R_{av} = \sqrt{\frac{B_1(\sigma_1^*/R_{av})^2 + B_2(\sigma_2^*/R_{av})^2}{2}}$

where $\sigma_1^*/R_{av} = \frac{0.1665}{1.5} = 0.111$ (last row, column 3 of Table 2a)

and $\sigma_2^*/R_{av} = \frac{0.1398}{1.5} = 0.0932$ (last row, column 6 of Table 2a)

so that $\sigma^*/R_{av} = 0.140$

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Table 2a

Calculation of Deviation σ^* for Signals in Figure 10

Time	R_1	(R_1-r_1)	$(R_1-r_1)^2$	R_2	(R_2-r_2)	$(R_2-R_2)^2$
0						
0.2						
.4						
.6						
.8						
1.0						
1.2						
1.4	.24	0	0			
1.6	.50	.26	.0676			
1.8	-.25	-.01	.0001			
2.0						
2.2	-.25	-.01	.0001			
2.4	-.50	-.26	.0676			
2.6						
2.8						
3.0						
3.2	.24	0	0			
3.4	.56	.32	.1024			
3.6	1.00	.76	.5776			
3.8	.30	.06	.0036			
4.0	-.30	-.06	.0036	1.24	0	0
4.2	-.24	0		1.50	.26	.0676
4.4	-.80	-.54	.2916	2.00	.76	.5776
4.6				1.30	.06	.0036
4.8				-1.35	-.11	.0121
5.0				-1.80	-.56	.3136
5.2						
5.4	.24	0	0			
5.6	.52	.28	.0784			
5.8				1.30	.06	.0036
6.0						
6.2						
6.4						
6.6						
6.8						
7.0						
7.2						
7.4						
7.6						
7.8						
8.0	.24	0	0			
8.2	.40	.16	.0256			
8.4	-.65	-.41	.1681			
8.6	-.27	-.03	.0009			
8.8						
9.0						
9.2						
9.4						
9.6						
9.8						
10.0						
$\Sigma(R_1-r_j)$ =			1.3872			.9781
$\frac{\Sigma(R_i-r)^2}{n}$ =			.0277			.01956
σ^*		σ_1^* =	0.1665			σ_2^* = 0.1398

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The example shows that the modified threshold deviation ratio criterion is relatively simple to apply. It should, however, be pointed out that it has not been extensively studied. Only 135 cases have been examined, plotted and used to develop the procedure. These have been selected from the earthquake records that were readily available. A broader range of signals should be used to examine the proposed criterion. Nevertheless, it appears to hold promise for establishing a relatively simple criterion that should be useful on a generic basis.

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3.0 COMBINATION OF TWO EARTHQUAKES AND THEIR RESPONSES

Further investigations were performed for the combination of two randomly selected real earthquakes and their responses. The purpose of this study was to see whether the data points thus obtained are located above the empirical curves or not. If the answer is affirmative, then one may conclude that in all probability, all earthquake-type loads can be combined by the SRSS rule. This effort was primarily directed to back-up the studies pertaining to items 2.1 and 2.2.

In the investigation of real earthquake time-histories, the characteristics of the loads and their responses were studied separately. This was done so that one could study the applicability of SRSS as the combination rule based on load or response characteristics. The 38 pairs of earthquakes were randomly selected from (9). The records were digitized in 0.02 second time intervals, and the earthquakes occurred mostly in southern California. The responses were obtained by applying the earthquakes to single-degree-of-freedom systems with different frequencies and subsequently to a multi-degree-of-freedom system.

3.1 SINGLE-DEGREE-OF-FREEDOM SYSTEM

The single-degree-of-freedom systems which were used had frequencies of 5, 10, and 15 Hz. the damping ratio selected was 2%. The peak values of the loads and the times of occurrence were recorded for each pair of earthquakes. In addition, the SRSS value of the two peaks was computed. Then a Monte Carlo analysis of the load histories was carried out with a uniformly distributed time lag τ of the second load with respect to the first one. The NEP of the SRSS was calculated from the internally computed CDF and recorded.

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Next, each pair of earthquakes was applied to the single-degree-of-freedom system, and the response histories of the same pair of earthquake peaks, SRSS, and NEP of SRSS were computed and obtained through the Monte Carlo simulation. The results are recorded in Tables 3, 4 and 5 with corresponding frequencies of 5, 10 and 15 Hz.

3.2 MULTI-DEGREE-OF-FREDDOM SYSTEMS

To investigate further the combination of earthquake type responses, the same 38 pairs of earthquakes were applied to a multi-degree-of-freedom system. The system chosen for study was a hypothetical two-loop reactor and piping systems consisting of an elastically supported reactor vessel, a steam generator, and pumps connected by piping with diameters of three and four feet (8). The thirty mode frequencies and participation factors are shown in Table 6a and 6b. The mode shapes are not shown here to save space, however, they can be obtained from Reference 8.

Computations similar to those performed for the single-degree-of-freedom system were carried out, and the results are given in Tables 7-10. The results in Table 7 correspond to truncation after the first seven modes and are based on motion only in the X-direction. Table 8 presents the results of considering the first 7 modes and motion in the Z-direction. Table 9 is for the first 9 modes and motion in the Z-direction. Table 10 is for 30 modes and motion in the X-direction.

3.3 CONCLUSIONS REGARDING THE COMBINATION OF EARTHQUAKE TYPE LOADS AND RESPONSES

Two conclusions can be drawn from the study of real earthquakes:

1) The SRSS design cirterion for the combined response should be applied only at the response level instead of at the load level, since

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the NEP of SRSS of the response level could be lower or higher than that of the load level.

2) The deviation ratio (σ/R_{max}) of the earthquakes are mostly below 0.37, either in the load or response level, except for a few cases marked * in the tables. The NEP of SRSS values are mostly above 0.5 except for a few of the over 250 cases studies. Therefore, if the earthquake loads are conservatively selected probabilistically at the 84th percentile level, then use of SRSS as the design rule may be considered acceptable. The statement of cause is based on the assumption that the other non-earthquake loads also must have deviation ratios of less than 0.37.

The results obtained by combining the real earthquakes and their responses are plotted in Figures 11 and 12 for single-degree-of-freedom systems, and in Figures 13 and 14 for the multi-degree-of-freedom systems. When a lower bound approach is adopted, the relationships between NEP of SRSS and the devaition ratio (σ/R_{max}) are:

1) A NEP of 0.84, and a (σ/R_{max}) of 0.19.

2) A NEP of 0.50, and a (σ/R_{max}) of over 0.40.

TABLE 3 EARTHQUAKE COMBINATION (15 sec duration) f = 5 Hz, ξ = 2 %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
1	Imperial Valley 5/18/40 (S00E)	341.70	2.12	0.227	401.124		.878	3.20	.281	1.046	
	5/18/40 (S90W)	210.10	11.44	0.253		.88	.563	8.02	.306		.79
2	Imperial Valley 5/18/40 (Vert.)	206.30	0.98	0.207	230.138		.389	0.90	.222	0.568	
	N.W. California 10/7/51 (S44N)	102.00	4.14	0.182		.89	.415	4.58	.194		.96
3	N.W. California 10/7/51 (N46W)	109.50	4.38	0.190	112.637		.285	5.52	.266	0.277	
	10/7/51 (Vert.)	26.40	3.00	0.302		.90	.085	6.06	.329		.75
4	Kern County Cal. 7/21/52 (S00E)	46.50	17.34	0.268	69.833		.075	7.50	.271	0.126	
	7/21/52 (S90W)	52.10	16.70	0.335		.86	.101	7.20	.303		.85
5	Kern County Cal. 7/21/52 (Vert.)	29.30	19.32	0.328	155.485		.083	7.04	.231	0.460	
	7/21/52 (N21E)	152.70	9.10	0.276		.76	.452	3.74	.411*		.60
6	Kern County Cal. 7/21/52 (S69E)	175.90	3.70	0.250	203.787		.533	9.20	.303	0.624	
	7/21/52 (Vert.)	102.90	9.76	0.265		.87	.325	6.84	.320		.77
7	Kern County Cal. 7/21/52 (N42E)	87.80	11.58	0.308	155.714		.182	4.60	.272	0.247	
	7/21/52 (S48E)	128.60	6.98	0.219		.93	.166	7.00	.223		.82
8	Kern County Cal. 7/21/52 (Vert.)	43.60	8.12	0.293	69.482		.164	9.26	.269	0.205	
	7/21/52 (S00N)	54.10	13.28	0.285		.85	.122	9.98	.303		.84

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TABLE 3 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) f = 5 Hz
ξ = 2 %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
9	Kern County Cal. 7/21/52 (N90E)	43.90	12.92	0.322	48.974		.096	7.48	.264	.114	
	7/21/52 (Vert.)	22.50	21.98	0.269		.79	.062	7.52	.285		.89
10	Kern Co. Cal. 7/21/52 (S00W)	58.10	13.30	0.270	71.225		.154	9.98	.280	.198	
	7/21/52 (N90E)	41.20	12.98	0.342		.91	.124	7.44	.215		.91
11	Kern County Cal. 7/21/52 (Vert.)	20.30	18.06	0.317	165.748		.061	5.50	.254	.459	
	Eureka 12/21/54 (N11W)	164.50	4.84	0.222		.72	.452	6.00	.197		.86
12	Eureka 12/21/54 (N79E)	252.70	3.84	0.210	265.456		.955	5.00	.228	.782	
	12/21/54 (Vert.)	81.30	0.16	0.196		.88	.228	3.56	.283		.84
13	Eureka 12/21/54(N44E)	155.70	6.88	0.271	251.336		.277	7.22	.226	.516	
	12/21/54(N46W)	197.30	7.10	0.186		.97	.422	7.00	.194		.91
14	Eurkeka 12/21/54 (Vert.)	41.90	8.00	0.306	108.608		.065	5.24	.347	.286	
	San Jose 9/4/55 (N31W)	100.20	1.20	0.173		.61	.279	1.46	.177		.57
15	San Jose 9/4/55 (N59E)	105.80	1.20	0.139	114.66		.534	1.44	.194	.555	
	9/4/55 (Vert.)	44.20	1.58	0.150		.97	.150	0.92	.186		.96
16	El Alamo Cal. 2/9/56 (S00W)	32.40	10.16	0.362	59.664		.109	8.86	.300	.199	
	2/9/56 (S90W)	50.10	6.80	0.314		.68	.167	11.90	.298		.76

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TABLE 3 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) $f = 5$ Hz, $\xi = 2$ %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
17	El Alamo Cal. 2/9/56 (Vert.)	12.40	9.48	0.317	17.117		.049	8.26	.376*	.054	
	2/9/56 (S00W)	11.80	1.10	0.255		.68	.020	5.28	.358		.59
18	El Alamo Cal. 2/9/56 (S90W)	15.40	0.66	0.267	15.749		.035	2.06	.293	.038	
	2/9/56 (Vert.)	3.30	0.00	0.305		.96	.015	4.60	.326		.69
19	San Francisco 3/22/57 (N45E)	45.90	1.76	0.195	64.209		.207	1.92	.206	.292	
	3/22/57 (N45W)	44.90	1.76	0.235		.98	.205	2.70	.224		.96
20	San Francisco 3/22/57 (Vert.)	26.30	2.78	0.240	47.653		.078	3.24	.243	.175	
	3/22/57 (S09W)	41.80	2.68	0.186		.89	.156	2.64	.180		.89
21	San Francisco 3/22/57 (N81E)	45.40	2.04	0.158	54.416		.144	3.66	.280	.221	
	3/22/57 (Vert.)	30.00	0.14	0.207		.95	.167	.92	.206		.84
22	San Francisco 3/22/57 (N10E)	81.00	1.34	0.131	131.374		.194	1.50	.144	.389	
	3/22/57 (S80E)	102.00	1.44	0.139		.97	.338	2.00	.199		.96
23	San Francisco 3/22/57 (Vert.)	37.20	1.18	0.125	91.686		.057	1.24	.205	.258	
	3/22/57 (S09E)	83.80	1.80	0.171		.94	.252	1.64	.204		.95
24	San Francisco 3/22/57 (S81W)	55.10	2.12	0.201	70.202		.206	1.60	.187	.243	
	3/22/57 (Vert.)	43.50	1.62	0.170		.95	.129	1.48	.211		.98

TABLE 3 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) $f = 5$ Hz, $\xi = 2$ %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
25	San Francisco 3/22/57 (N26E)	39.00	0.48	.159	45.636	.91	.144	.64	.164	.160	.83
	3/22/57 (S64E)	23.70	1.26	.201			.070	2.74	.247		
26	San Francisco 3/22/57 (Vert.)	15.30	0.34	.201	65.220	.92	.056	2.76	.187	.201	.91
	Hollister 4/8/61 (S01W)	63.40	1.04	.348			.193	2.00	.245		
27	Hollister 4/8/61 (W89W)	175.70	1.20	.181	182.431	.76	.324	1.26	.189	.346	.89
	4/8/61 (N89W)	49.10	1.28	.214			.121	1.34	.191		
28	Borrego Mount. 4/8/68 (S00W)	127.88	8.54	.184	139.651	.89	.247	6.92	.239	.308	.79
	4/8/68 (S90W)	56.30	15.00	.313			.184	3.06	.364		
29	Borrego Mount. 4/6/68 (Vert.)	29.70	7.56	.269	41.861	.89	.131	9.62	.332	.157	.87
	4/6/68 (S00W)	29.50	8.54	.236			.087	9.60	.252		
30	Borrego Mount. 4/8/68 (N90E)	28.90	8.62	.264	31.567	.90	.084	9.22	.233	.095	.87
	4/8/68 (Vert.)	12.70	10.90	.278			.045	7.12	.304		
31	Long Beach 3/10/33 (S08W)	130.60	1.88	.226	200.021	.97	.372	2.24	.210	.495	.97
	3/10/33 (N82W)	151.50	2.14	.174			.327	2.20	.221		
32	Long Beach 3/10/33 (N82W)	149.50	1.00	.109	155.644	.97	.381	1.96	.236	.392	.71
	Southern Cal. 10/2/33 (N00E)	43.30	0.20	.261			.090	4.32	.313		

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TABLE 3 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) $f = 5$ Hz, $\xi = 2\%$

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
33	Southern Cal. 10/2/33 (N90E)	85.40	0.22	0.343	89.506		.169	3.36	.294	.178	
	10/2/33 (S0WN)	26.80	0.22	0.271		.92	.057	1.54	.326		.88
34	Southern Cal. 10/2/33 (N00E)	32.10	0.12	0.184	41.561		.072	.300	.263	.098	
	10/2/33 (N90W)	26.40	0.28	0.234		.92	.066	.46	.249		.91
35	Southern Cal. 10/2/33 (S0WN)	10.70	2.34	0.359	157.165		.023	.52	.286	.618	
	Lower Cal. 12/30/34 (S00W)	15 .80	3.32	0.280		.89	.618	4.40	.306		.87
36	Lower Cal. 12/30/34 (S90W)	179.10	15.12	0.220	191.61		.555	2.86	.274	.595	
	12/30/34 (Vert.)	68.10	3.40	0.268		.86	.214	3.42	.299		.72
37	Helena, Montana 10/31/35 (S00W)	143.50	3.04	0.121	202.234		.216	2.02	.156	.482	
	10/31/35 (S90W)	142.20	2.42	0.154		.96	.431	2.63	.142		.97
38	Helena, Montana 10/31/35 (S0WN)	87.50	2.32	0.146	165.858		.198	2.20	.176	.410	
	N.W. California 9/11/38 (N45E)	140.90	2.26	0.143		.99	.359	2.40	.175		.97

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TABLE 4 EARTHQUAKE COMBINATION (15 sec duration) $f = 10$ Hz, $\xi = 2$ %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
1	Imperial Valley 5/18/40 (S00E)	341.70	2.12	0.227	401.124	.88	.174	5.00	.206	.188	.91
	5/18/40 (S90W)	210.10	11.44	0.253			.073	.24	.263		
2	Imperial Valley 5/18/40 (Vert.)	206.30	0.98	0.207	230.138	.88	.290	1.42	.191	.294	.70
	N.W. California 10/7/51 (S44N)	102.00	4.14	0.182			.045	3.30	.180		
3	N.W. California 10/7/51 (N46W)	109.50	4.38	0.190	112.637	.90	.034	4.38	.236	.036	.89
	10/7/51 (Vert.)	26.40	3.00	0.302			.012	3.02	.231		
4	Kern County Cal. 7/21/52 (S00E)	46.50	17.34	0.268	69.833	.86	.013	7.54	.236	.018	.91
	7/21/52 (S90W)	52.10	16.70	0.335			0.13	7.48	.312		
5	Kern County Cal. 7/21/52 (Vert.)	29.30	19.32	0.328	155.485	.76	.010	3.62	.296	.056	.76
	7/21/52 (N21E)	152.70	9.10	0.276			.055	8.20	.276		
6	Kern County Cal. 7/21/52 (S69E)	175.90	3.70	0.250	203.787	.87	.049	6.54	.308	.075	.70
	7/21/52 (Vert.)	102.90	9.76	0.265			.057	5.92	.276		
7	Kern County Cal. 7/21/52 (N42E)	87.80	11.58	0.308	155.714	.93	.021	7.52	.298	.036	.92
	7/21/52 (S48E)	128.60	6.98	0.219			.029	6.98	.218		
8	Kern County Cal. 7/21/52 (Vert.)	43.60	8.12	0.293	69.482	.85	.014	8.12	.302	.019	.81
	7/21/52 (S00N)	54.10	13.28	0.285			.013	7.52	.296		

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TABLE 4 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) f = Hz, ξ = 2%

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
9	Kern County Cal. 7/21/52 (N90E)	43.90	12.92	0.322	48.974	.79	.012	7.52	.285	.013	.77
	7/21/52 (Vert.)	22.50	21.98	0.269			.005	7.52	.296		
10	Kern County Cal. 7/21/52 (S00W)	58.10	13.30	0.270	71.225	.91	.016	7.54	.272	.020	.71
	7/21/52 (N90E)	41.20	12.98	0.342			.013	9.52	.308		
11	Kern County Cal. 7/21/52 (Vert.)	20.30	18.06	0.317	165.748	.72	.008	1.14	.277	.057	.79
	Eureka 12/21/54 (N11W)	164.50	4.84	0.222			.056	6.46	.209		
12	Eureka 12/21/54 (N79E)	252.70	3.84	0.210	265.456	.88	.083	4.98	.188	.099	.84
	12/21/54 (Vert.)	81.30	0.16	0.196			.055	1.08	.212		
13	Eureka 12/21/54 (N44E)	155.70	6.88	0.271	251.336	.97	.050	6.86	.213	.070	.95
	12/21/54 (N46W)	197.30	7.10	0.186			.049	7.08	.185		
14	Eureka 12/21/54 (Vert.)	41.90	8.00	0.306	108.608	.61	.013	1.70	.298	.030	.73
	San Jose 9/4/55 (N31W)	100.20	1.20	0.173			.028	0.94	.170		
15	San Jose 9/4/55 (N59E)	105.80	1.20	0.139	114.66	.97	.039	1.20	.123	.047	.97
	9/4/55 (Vert.)	44.20	1.58	0.150			.026	1.66	.172		
16	El Alamo Cal. 2/9/56 (S00W)	32.40	10.16	0.362	59.664	.68	.012	8.92	.303	.018	.77
	2/9/56 (S90W)	50.10	6.80	0.314			.013	6.80	.313		

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TABLE 4 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) f = Hz
ξ = 2%

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
17	El Alamo Cal. 2/9/56 (Vert.)	12.40	9.48	0.317	17.117	.68	.0089	6.60	.278	.009	.68
	2/9/56 (S00W)	11.48	1.10	0.255			.0028	1.12	.277		
18	El Alamo Cal. 2/9/56 (S90W)	15.40	0.66	0.267	15.749	.96	.0037	1.82	.274	.004	.95
	2/9/56 (Vert.)	3.30	0.00	0.305			.0014	1.40	.294		
19	San Francisco 3/22/57 (N45E)	45.90	1.76	0.195	64.209	.98	.015	1.76	.176	.021	.94
	3/22/57 (N47W)	44.90	1.76	0.235			.014	2.82	.212		
20	San Francisco 3/22/57 (Vert.)	26.80	2.78	0.230	49.653	.89	.019	1.86	.197	.034	.95
	3/22/57 (S09W)	41.80	2.68	0.186			.020	2.54	.139		
21	San Francisco 3/22/57 (N81E)	45.40	2.04	0.158	54.416	.95	.014	2.42	.200	.019	.89
	3/22/57 (Vert.)	30.00	0.14	0.207			.012	2.06	.265		
22	San Francisco 3/22/57 (N10E)	81.80	1.34	0.131	131.374	.97	.037	1.34	.168	.067	.94
	3/22/57 (S80E)	102.80	1.44	0.139			.056	2.36	.188		
23	San Francisco 3/22/57 (Vert.)	37.20	1.18	0.125	91.686	.94	.017	1.18	.214	.049	.92
	3/22/57 (S09E)	83.80	1.80	0.171			.046	2.10	.155		
24	San Francisco 3/22/57 (S81W)	55.10	2.12	0.201	70.202	.95	.030	2.12	.168	.035	.94
	3/22/57 (Vert.)	43.50	1.62	0.170			.017	1.92	.197		

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TABLE 4 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) $f = 10$ Hz, $\xi = 2$ %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
25	San Francisco 3/22/57 (N26E)	39.00	0.48	.159	45.636	.91	.015	.58	.169	.020	.96
	3/22/57 (S64E)	23.70	1.26	.201			.013	1.26	.151		
26	San Francisco 3/22/57 (Vert.)	15.30	0.34	.201	65.220	.92	.011	1.98	1.85	.022	.90
	Hollister 4/8/61 (S01W)	63.40	1.04	.348			.019	1.98	.306		
27	Hollister. 4/8/61 (N89W)	175.70	1.20	.181	182.431	.76	.049	1.20	.159	.050	.72
	4/8/61 (N89W)	49.10	1.28	.214			.012	1.48	.255		
28	Borrego Mount. 4/8/68 (S00W)	127.80	8.54	.184	139.651	.89	.035	7.52	.171	.040	.88
	4/8/68 (S90W)	56.30	15.00	.313			.019	6.06	.280		
29	Borrego Mount. 4/6/68 (Vert.)	29.70	7.56	.269	41.861	.89	.026	8.18	.242	.028	.92
	4/6/68 (S00W)	29.50	8.54	.236			.010	9.06	.197		
30	Borrego Mount. 4/8/68 (N90E)	28.90	8.62	.264	31.567	.90	.0097	9.16	.241	.010	.75
	4/8/68 (Vert.)	12.70	10.90	.278			.0043	8.50	.307		
31	Long Beach 3/10/33 (S08W)	130.60	1.88	.226	200.021	.97	.068	2.18	.205	.083	.97
	3/10/33 (N82W)	151.50	2.14	.174			.048	1.84	.187		
32	Long Beach 3/10/33 (N82W)	149.50	1.00	.109	155.644	.97	.046	1.06	.218	.048	.95
	Southern Cal. 10/2/23	43.30	0.20	.281			.013	.18	.221		

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TABLE 4 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) f = 10 Hz
ξ = 2 %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
33	Southern Cal. 10/2/33 (N90E)	85.40	0.22	0.343	89.506	.92	.027	.24	.257	.030	.97
	10/2/33 (S0WN)	26.80	0.22	0.271			.013	.22	.201		
34	Southern Cal. 10/2/33 (N00E)	32.10	0.12	0.184	41.561	.92	.0098	.10	.173	.013	.98
	10/2/33 (N90W)	26.40	0.28	0.234			.0089	.06	.196		
35	Southern Cal. 10/2/33 (S0WN)	10.70	2.34	0.359	157.165	.89	.0042	2.36	.249	.063	.84
	Lower Cal. 12/30/34 (S00W)	156.80	3.32	0.280			.063	4.36	.296		
36	Lower Cal. 12/30/34 (S90W)	179.10	15.12	0.220	191.61	.86	.097	2.82	.175	.115	.95
	12/30/34 (Vert.)	68.10	3.40	0.268			.060	1.78	.272		
37	Helena, Montana 10/31/35 (S00W)	143.50	3.04	0.121	202.234	.96	.067	3.10	.176	.086	.95
	10/31/35 (S90W)	142.50	2.42	0.154			.054	2.50	.153		
38	Helena, Montana 10/31/35 (S0WN)	87.50	2.32	0.146	165.858	.99	.057	2.78	.154	.069	.96
	N.W. California 9/11/38 (N45E)	140.00	2.26	0.143			.039	2.28	.188		

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TABLE 5 EARTHQUAKE COMBINATION (15 sec duration) $f = 15$ Hz, $\xi = 2$ %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
1	Imperial Valley 5/18/40 (S00E)	341.70	2.12	0.227	401.124	.88	0.0478	2.60	0.197	0.052	.93
	5/18/40 (S90W)	210.10	11.44	0.253			0.0202	0.22	0.259		
2	Imperial Valley 5/18/40 (Vert.)	206.30	0.98	0.207	230.138	.88	0.0487	0.94	.220	.049	.65
	N.W. California 10/7/51 (S44W)	102.00	4.14	0.182			.0082	4.14	.199		
3	N.W. California 10/7/51 (N46W)	109.50	4.38	0.190	112.637	.90	.0086	4.38	.205	.009	.88
	10/7/51 (Vert.)	26.40	3.00	0.302			.0036	4.50	.212		
4	Kern County Cal. 7/21/52 (S00E)	46.50	17.34	0.268	69.833	.86	.0037	7.48	.269	.005	.77
	7/21/52 (S90W)	52.10	16.70	0.335			.0042	7.60	.327		
5	Kern County Cal. 7/21/52 (Vert.)	29.30	19.32	0.328	155.485	.76	.0024	7.50	.329	.014	.76
	7/21/52 (N21E)	152.70	9.10	0.276			.0139	7.50	.262		
6	Kern County Cal. 7/21/52 (S69E)	175.90	3.70	0.250	203.787	.87	.0154	3.72	.245	.018	.90
	7/21/52 (Vert.)	102.90	9.76	0.265			.0099	7.50	.251		
7	Kern County Cal. 7/21/52 (N42E)	87.80	11.58	0.308	155.714	.93	.0069	7.50	.309	.012	.93
	7/21/52 (S48E)	128.60	6.98	0.219			.0102	6.98	.214		
8	Kern County Cal. 7/21/52 (Vert.)	43.60	8.12	0.293	69.482	.85	.0037	8.04	.303	.006	.87
	7/21/52 (S00N)	54.10	13.28	0.285			.0050	7.50	.246		

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TABLE 5 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) ± = 17 Hz
ξ = 2 %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
9	Kern County Cal. 7/21/52 (N90E)	43.50	12.92	0.322	48.974		.0039	7.50	.287	.004	
	7/21/52 (Vert.)	22.50	21.98	0.269		.79	.0018	7.50	.278		.83
10	Kern County Cal. 7/21/52 (S00W)	58.10	13.30	0.270	71.225		.0047	7.50	.275	.006	
	7/21/52 (N90E)	41.20	12.98	0.342		.91	.0041	7.46	.280		.89
11	Kern County Cal. 7/21/52 (Vert.)	20.30	18.06	0.317	165.748		.0024	8.86	.292	.013	
	Eureka 12/21/54 (N11W)	164.50	4.84	0.222		.72	.0129	6.46	.232		.67
12	Eureka 12/21/54 (N79E)	252.70	3.84	0.210	265.456		.0199	3.48	.219	.023	
	12/21/54 (Vert.)	81.30	0.16	0.196		.88	.0105	.160	.169		.84
13	Eureka 12/21/54 (N44E)	155.70	6.88	0.271	251.336		.0125	6.88	.265	.021	
	12/21/54 (N46W)	197.30	7.10	0.186		.97	.0175	7.10	.168		.97
14	Eureka 12/21/54 (Vert.)	41.90	8.00	0.306	108.608		.0035	7.50	.303	.010	
	San Jose 9/4/55 (N31W)	*100.20	1.20	0.173		.61	.0097	*1.22	.148		.72
15	San Jose 9/4/55 (N59E)	105.80	1.20	0.139	114.66		.0111	1.22	.127	.012	
	9/4/55 (Vert.)	44.20	1.58	0.150		.97	.0047	1.58	.157		.96
16	El Alamo Cal. 2/ /56 (S00W)	32.40	10.16	0.362	59.664		.0028	4.94	.348	.005	
	2/9/56 (S90W)	50.10	6.80	0.314		.68	.0043	6.80	.296		.74

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TABLE 5 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) $f = 15$ Hz, $\xi = 2$ %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
17	El Alamo Cal. 2/9/56 (Vert.)	12.40	9.48	0.317	17.117	.68	.0017	7.50	.234	.002	.91
	2/9/56 (S00W)	11.80	1.10	0.255			.0011	1.10	.223		
18	El Alamo Cal. 2/9/56 (S90W)	15.40	0.66	0.267	15.749	.96	.0013	.68	.256	.001	.97
	2/9/56 (Vert.)	3.30	0.00	0.305			.0004	.12	.250		
19	San Francisco 3/22/57 (N45E)	45.90	1.76	0.195	64.209	.98	.0035	1.74	.215	.0052	.88
	3/22/57 (N47W)	44.90	1.76	0.235			.0038	2.80	.236		
20	San Francisco 3/22/57 (Vert.)	26.80	2.78	0.230	49.653	.89	.0037	1.56	.217	.006	.94
	3/22/57 (S09W)	41.80	2.68	0.186			.0051	2.38	.145		
21	San Francisco 3/22/57 (N81E)	45.40	2.04	0.158	54.416	.95	.0044	2.04	.143	.006	.96
	San Francisco 3/22/57 (Vert.)	30.00	0.14	0.207			.0035	.34	.133		
22	San Francisco 3/27/57 (N10E)	81.88	1.34	0.131	131.374	.97	.0086	1.36	.145	.014	.97
	3/27/57 (S80E)	102.80	1.44	0.139			.0110	1.44	.136		
23	San Francisco 3/22/57 (Vert.)	37.20	1.18	0.125	91.686	.94	.0052	2.30	.163	.009	.97
	3/22/57 (S09E)	63.80	1.80	0.171			.0079	1.80	.157		
24	San Francisco 3/22/57 (S81W)	55.10	2.12	0.201	70.202	.95	.0053	2.44	.194	.007	.92
	3/22/57 (Vert.)	43.50	1.62	0.170			.0046	1.64	.188		

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TABLE 5 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration) f = 15 Hz
ξ = 2 %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
25	San Francisco 3/22/57 (N26E)	39.00	0.48	.159	45.636		.0037	.60	.157	.004	
	3/22/57 (S64E)	23.70	1.26	.201		.91	.0023	1.26	.203		.91
26	San Francisco 3/22/57 (Vert.)	15.30	0.34	.201	65.280		.0036	1.88	.213	.007	
	Hollister 4/8/61 (S01W)	63.40	1.04	.348		.92	.0059	1.96	.306		.81
27	Hollister 4/8/61 (N89W)	175.70	1.20	.181	182.431		.0140	1.20	.181	.014	
	4/8/61 (N89W)	49.10	1.28	.214		.76	.0038	1.30	.238		.74
28	Borrego Mount. 4/8/68 (S00W)	127.10	8.54	.184	139.651		.0118	7.50	.162	.013	
	4/8/68 (S90W)	56.30	15.00	.313		.89	.0047	7.50	.313		.87
29	Borrego Mount. 4/6/68 (Vert.)	29.70	7.56	.269	41.861		.0037	6.42	.307	.004	
	4/6/68 (S00W)	29.50	8.54	.236		.89	.0026	7.50	.224		.72
30	Borrego Mount. 4/8/68 (N90E)	28.90	8.62	.264	31.567		.0024	7.50	.256	.003	
	4/8/68 (Vert.)	12.70	10.90	.278		.90	.0014	7.52	.250		.84
31	Long Beach 3/10/33 (S08W)	130.60	1.88	.226	200.021		.0164	2.16	.225	.021	
	3/10/33 (N82W)	151.50	2.14	.174		.97	.0127	1.74	.203		.91
32	Long Beach 3/10/33 (N82W)	149.50	1.00	.109	155.644		.0151	1.94	.200	.016	
	Southern Cal. 10/2/33) (N003)	43.30	0.20	.281		.97	.0049	.20	.206		.93

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TABLE 5 (CONTINUED) EARTHQUAKE COMBINATION (15 sec duration) f = 15 Hz, ξ = 2 %

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
33	Southern Cal. 10/2/33 (N90E)	85.40	0.22	0.343	89.506		.0076	.48	.306	.009	
	10/2/33 (S0WN)	26.80	0.22	0.271		.92	.0038	.22	.204		.92
34	Southern Cal. 10/2/33 (N00E)	32.10	0.12	0.184	41.561		.0036	.12	.146	.005	
	10/2/33 (N90W)	26.40	0.28	0.234		.92	.0032	.04	.173		.99
35	Southern Cal. 10/2/33 (S0WN)	10.70	2.34	0.359	157.165		.0012	2.34	.276	.024	
	Lower Cal. 12/30/34 (S00W)	156.80	3.32	0.280		.89	.024	10.12	.215		.65
36	Lower Cal. 12/30/34 (S90W)	179.10	15.12	0.220	191.61		.0219	7.52	.184	.025	
	12/30/34 (Vert.)	68.10	3.40	0.268		.86	.0112	2.26	.275		.88
37	Helena, Montana 10/31/35 (S00W)	143.50	3.04	0.121	202.234		.0250	2.64	.121	.032	
	10/31/35 (S90W)	142.50	2.42	0.154		.96	.0200	2.48	.132		.98
38	Helena, Montana 10/31/35 (S0WN)	87.50	2.32	0.146	165.858		.0132	2.72	.178	.017	
	N.W. California 9/11/38 (N45E)	140.90	2.26	0.143		.99	.0116	2.28	.151		.99

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TABLE 6A
FREQUENCIES

MODE	CYCLE/SEC	MODE	CYCLE/SEC
1	6.045	16	14.390
2	6.096	17	14.420
3	6.348	18	15.820
4	6.353	19	25.320
5	6.473	20	25.380
6	6.480	21	26.660
7	6.676	22	26.670
8	7.994	23	29.820
9	9.974	24	30.380
10	10.320	25	30.380
11	11.920	26	30.490
12	12.300	27	30.800
13	12.710	28	35.440
14	12.860	29	35.660
15	13.700	30	35.730

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TABLE 6B
PARTICIPATION FACTORS

MODE	X-DIRECTION	Z-DIRECTION	MODE	X-DIRECTION	Z-DIRECTION
1	-.2274E-10	-.4831-09	16	-.1180E+02	
2	-.1578E-10	.1077E+02	17	-.6946E-10	
3	.1411E+02	-.4738E-10	18	-.4771E+02	
4	-.6788E-08	.2521E-9	19	.1784E-06	
5	.1147E-10	.5854E+02	20	-.3799E-07	
6	.6017E-10	.9629E-08	21	.2708E-07	
7	-.1183E+02	-.3003E-10	22	-.4111E+01	
8	-.3809E-11	-.3809E-11	23	.6175E-06	
9	.9901E+02	.9001E+02	24	.2266E-04	
10	.3136E-10		25	.1716E-03	
11	-.4691E-10		26	-.1198E+01	
12	-.6814E-10		27	-.1836E-05	
13	.3548E-10		28	.750DE-03	
14	-.5708E+01		29	.2643E-03	
15	.9140E-1Z		30	-.5261E+01	

TABLE 7 EARTHQUAKE COMBINATION (15 sec duration) X-direction
7 DEGREES OF FREEDOM

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
1	Imperial Valley 5/18/40 (S00E)	341.70	2.12	0.227	401.124	.88	5.8957	4.14	.281	6.974	.81
	5/18/40 (S90W)	210.10	11.44	0.253			3.7247	6.14	.315		
2	Imperial Valley 5/18/40 (Vert.)	206.30	0.98	0.207	230.138	.88	3.793	1.72	.315	4.564	.89
	N.W. California 10/7/51 (S44W)	102.00	4.14	0.182			2.538	4.16	.222		
3	N.W. California 10/7/51 (N46W)	109.50	4.38	0.190	112.637	.90	2.310	5.06	.274	2.34	.87
	10/7/51 (Vert.)	26.40	3.00	0.302			.368	4.16	.311		
4	Kern County Cal. 7/21/52 (S00E)	46.50	17.34	0.268	69.833	.86	.303	7.50	.33	.377	.74
	7/21/52 (S90W)	52.10	16.70	0.335			.225	12.86	.32		
5	Kern County Cal. 7/21/52 (Vert.)	29.30	19.32	0.328	155.485	.76	.386	8.88	.362	3.584	.65
	7/21/52 (N21E)	152.70	9.10	0.276			3.563	11.52	.312		
6	Kern County Cal. 7/21/52 (S69E)	175.90	3.70	0.250	203.787	.87	3.556	6.54	.305	4.30	.81
	7/21/52 (Vert.)	102.90	9.76	0.265			2.418	2.50	.337		
7	Kern County Cal. 7/21/52 (N42E)	87.80	11.58	0.308	155.714	.93	.445	12.98	.320	.672	.88
	7/21/52 (S48E)	128.60	6.98	0.219			.504	8.92	.276		
8	Kern County Cal. 7/21/52 (Vert.)	43.60	8.12	0.293	69.482	.85	2.118	8.80	.272	2.259	.85
	7/21/52 (S00W)	54.10	13.28	0.285			.788	8.90	.267		

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TABLE 7 (CONTINUE) EARTHQUAKE COMBINATION (15 . duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
9	Kern County Cal. 7/21/52 (N90E)	43.90	12.92	0.322	48.974	.79	.3623	9.20	.294	.477	.79
	7/21/52 (Vert.)	22.50	21.98	0.269			.3107	2.54	.325		
10	Kern County Cal. 7/21/52 (S00W)	58.10	13.30	0.270	71.225	.91	1.119	8.12	.285	1.237	.83
	7/21/52 (N90E)	41.20	12.98	0.342			.528	9.50	.322		
11	Kern County Cal. 7/21/52 (Vert.)	20.30	18.06	0.317	165.748	.72	.539	5.64	.332	2.669	.79
	Eureka 12/21/54 (N11W)	164.50	4.84	0.222			2.615	4.40	.206		
12	Eureka 12/21/54 (N79E)	252.70	3.84	0.210	265.456	.88	3.351	3.96	.246	3.592	.79
	12/21/54 (Vert.)	81.30	0.16	0.196			1.295	7.42	.386		
13	Eureka 12/21/54 (N44E)	155.70	6.88	0.271	251.336	.97	1.609	8.08	.208	2.608	.95
	12/21/54 (N46W)	197.30	7.10	0.186			2.052	7.84	.221		
14	Eureka 12/21/54 (Vert.)	41.90	8.00	0.306	108.608	.61	.336	8.40	.335	.853	.54
	San Jose 9/4/55 (N31W)	100.20	1.20	0.173			.784	2.16	.246		
15	San Jose 9/4/55 (N59E)	105.80	1.20	0.139	114.66	.97	1.025	1.10	.325	1.201	.85
	9/4/55 (Vert.)	44.20	1.58	0.150			.626	1.68	.235		
16	El Alamo Cal. 2/9/56 (S00W)	32.40	10.16	0.362	59.664	.68	.658	2.52	.372*	.844	.60
	2/9/56 (S90W)	50.10	6.80	0.314			.529	10.74	.318		

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TABLE 7 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
17	El Alamo Cal. 2/9/56 Vert.	12.40	9.48	0.317	17.117		.443	11.92	.337	.462	
	2/9/56 S00W	11.80	1.10	0.255		.68	.130	11.82	.497*		.63
18	El Alamo Cal. 2/9/56 S90W	15.40	0.66	0.267	15.749		.120	2.02	.352	.16	
	2/9/56 Vert.	3.30	0.00	0.305		.96	.101	4.94	.296		.72
19	San Francisco 3/22/57 N45E	45.90	1.76	0.195	64.209		.873	2.68	.241	1.188	
	3/22/57 Vert.	44.90	1.76	0.235		.98	.806	3.64	.262		.91
20	San Francisco 3/22/57 Vert	26.80	2.78	0.240	49.653		.618	1.34	.262	.705	
	3/22/57 S09W	41.80	2.68	0.186		.89	.341	6.20	.359		.64
21	San Francisco 3/22/57 N81E	45.40	2.04	0.158	54.416		.532	4.94	.275	.856	
	3/22/57 Vert.	30.00	0.14	0.207		.95	.671	1.48	.237		.89
22	San Francisco 3/22/57 N10E	81.80	1.34	0.131	131.374		2.202	2.58	.235	2.758	
	3/22/57 S80E	102.80	1.44	0.139		.97	1.660	1.86	.194		.94
23	San Francisco 3/22/57 Vert	37.20	1.18	0.125	91.686		1.003	1.78	.182	1.569	
	3/22/57 S09E	83.80	1.80	0.171		.94	1.208	1.92	.217		.95
24	San Francisco 3/22/57 S81W	55.10	2.12	0.201	70.202		.836	1.74	.248	1.073	
	3/22/57 Vert	43.50	1.62	0.170		.95	.672	2.70	.295		.87

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TABLE 7 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
25	San Francisco 3/22/57 (N25E)	39.00	0.48	.159	45.636		.801	1.90	.217	1.266	
	3/22/57 (S64E)	23.70	1.26	.201		.91	.980	2.26	.256		.93
26	San Francisco 3/22/57 (Vert.)	15.30	0.34	.201	65.220		.452	3.10	.236	1.541	
	Hollister 4/8/61 (S01W)	63.40	1.04	.348		.92	1.474	2.74	.241		.88
27	Hollister 4/8/61 (N89W)	175.70	1.20	.181	182.431		1.899	2.58	.211	1.963	
	4/8/61 (N89W)	49.10	1.28	.214		.76	.494	1.72	.339		.93
28	Borrego Mount. 4/8/68 (S00W)	127.80	8.54	.184	139.651		1.754	10.44	.305	1.922	
	4/8/68 (S90W)	56.30	15.00	.313		.89	.786	6.54	.350		.68
29	Borrego Mount. 4/6/68 (Vert)	29.70	7.56	.269	41.861		.6003	12.14	.369	.663	
	4/6/68 (S00W)	29.50	8.54	.236		.89	.282	9.56	.348		.71
30	Borrego Mount. 4/8/68 (N90E)	38.90	8.62	.264	31.567		.280	7.9	.343	.337	
	4/8/68 (Vert)	12.70	10.90	.278		.90	.187	8.52	.363		.72
31	Long Beach 3/10/33 (S08W)	130.60	1.88	.226	200.021		2.012	1.98	.280	2.379	
	3/10/33 (N82W)	151.50	2.14	.174		.97	1.2714	2.12	.281		.82
32	Long Beach 3/10/33 (N82W)	149.50	1.00	.109	155.644		2.3133	1.90	.252	2.332	
	Southern Cal. 10/2/33 (N00E)	43.30	0.20	.281		.97	.299	7.60	.317		.66

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TABLE 7 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
33	Southern Cal. 10/2/33 (N90E)	85.40	0.22	0.343	89.506		.4904	2.00	.344	.695	
	10/2/33 (DOWN)	26.80	0.22	0.271		.92	.4920	3.12	.351		.76
34	Southern Cal. 10/2/33 (N00E)	32.10	0.12	0.184	41.561		.298	1.92	.270	.433	
	10/2/33 (N90W)	26.40	0.28	0.234		.92	.3146	.96	.227		.90
35	Southern Cal. 10/30/33 (S0WN)	10.70	2.34	0.359	157.165		.1912	.88	.246	2.533	
	Lower Cal. 12/30/34 (S00W)	156.80	3.32	0.280		.89	2.526	5.86	.425		.73
36	Lower Cal. 12/30/34 (S90W)	179.10	15.12	0.220	191.61		3.034	2.62	.235	3.421	
	12/30/34 (Vert)	68.10	3.40	0.268		.86	1.5798	3.10	.325		.74
37	Helena, Montana 10/31/35 (S0WN)	143.50	3.04	0.121	202.234		3.4274	3.64	.234	3.93	
	10/31/35 (S90W)	142.50	2.42	0.154		.96	2.0193	3.12	.211		.92
38	Helena, Montana 10/31/35 (S0WN)	87.50	2.32	0.146	165.858		1.552	2.34	.273	2.90	
	N.W. California 9/11/38 (N45E)	140.90	2.26	0.143		.99	2.4545	3.72	.269		.89

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TABLE 8 EARTHQUAKE COMBINATION (15 sec duration) in Z-direction
7 DEGREES OF FREEDOM

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
1	Imperial Valley 5/18/40 (S00E)	341.70	2.12	0.227	401.124	.88	28.327	3.56	.293	34.52	.67
	5/18/40 (S90W)	210.10	11.44	0.253			19.736	5.80	.303		
2	Imperial Valley 5/18/40 (Vert.)	206.30	0.98	0.207	230.138	.88	20.273	0.62	.251	23.61	.89
	N.W. California 10/7/51 (S44W)	102.00	4.14	0.182			12.094	4.14	.216		
3	N.W. California 10/7/51 (N46W)	109.50	4.38	0.190	112.637	.90	12.596	4.26	.219	12.80	.70
	10/7/51 (Vert.)	26.40	3.00	0.302			2.302	6.16	.281		
4	Kern County Cal. 7/21/52 (S00E)	46.50	17.34	0.268	69.833	.86	2.681	7.48	.230	4.01	.90
	7/21/52 (S90W)	52.10	16.70	0.335			2.988	7.90	.279		
5	Kern County (Cal) 7/21/52 (Vert.)	29.30	19.32	0.328	155.485	.76	2.528	4.30	.305	16.26	.67
	7/21/52 (N21E)	152.70	9.10	0.276			16.065	10.64	.326		
6	Kern County Cal. 7/21/52 (S69E)	175.90	3.70	0.250	203.787	.87	18.345	6.52	.286	21.51	.69
	7/21/52 (Vert.)	102.90	9.76	0.265			11.238	5.00	.326		
7	Kern County Cal. 7/21/52 (N42E)	87.80	11.58	0.308	155.714	.93	4.482	3.90	.305	6.92	.78
	7/21/52 (S48E)	128.60	6.98	0.219			5.272	6.96	.252		
8	Kern County Cal. 7/21/52 (Vert.)	43.60	8.12	0.293	69.482	.85	9.99	8.14	.234	10.89	.87
	7/21/52 (S00W)	54.10	13.28	0.285			4.337	8.10	.266		

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TABLE 8 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
9	Kern County Cal. 7/21/52 (N90E)	43.50	12.92	0.322	48.974		2.548	9.18	.307	3.06	
	7/21/52 (Vert)	22.50	21.98	0.269		.79	1.692	1.04	.298		.65
10	Kern Co. Cal. ~~7/21/52 (S00W)~~	58.10	13.30	0.270	71.225		6.50	8.10	.234	7.67	
	7/21/52 (N90E)	41.20	12.98	0.342		.91	4.08	9.14	.245		.89
11	Kern County Cal. 7/21/52 (Vert)	20.30	18.06	0.317	165.748		2.92	4.92	.258	15.16	
	Eureka 12/21/54 (N11W)	164.50	4.84	0.222		.72	14.88	3.82	.201		.74
12	Eureka 12/21/54 (N79E)	252.70	3.84	0.210	265.456		24.96	3.62	.183	26.54	
	12/21/54 (Vert)	81.30	0.16	0.196		.88	9.01	0.18	.244		.90
13	Eureka 12/21/54 (N44E)	155.70	6.88	0.271	251.336		11.201	7.18	.203	21.012	
	12/21/54 (N46W)	197.30	7.10	0.186		.97	17.78	7.12	.139		.96
14	Eureka 12/21/54 (Vert)	41.90	8.00	0.306	108.608		2.648	7.20	.279	8.12	
	San Jose 9/4/55 (N31W)	100.20	1.20	0.173		.61	7.676	1.22	.189		.56
15	San Jose 9/4/55 (59E)	105.80	1.20	0.139	114.66		10.459	1.10	.182	11.43	
	9/4/55 (Vert)	44.20	1.58	0.150		.97	4.617	1.66	.204		.91
16	El Alamo Cal. 2/9/56 (S00W)	32.40	10.16	0.362	59.664		3.582	2.52	.324	5.233	
	2/9/56 (S90W)	50.10	6.80	0.314		.68	3.815	10.40	.274		.76

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TABLE 8 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
17	El Alamo Cal. 2/9/56 Vert	12.40	9.48	0.317	17.117		1.907	11.34	.355	2.088	
	2/9/56 S00W	11.80	1.10	0.255		.68	.849	4.74	.323		.43
18	El Alamo Cal. 2/9/56 S90W	15.40	0.66	0.267	15.749		1.123	2.00	.226	1.219	
	2/9/56 Vert.	3.30	0.00	0.305		.96	.475	4.60	.279		.76
19	San Francisco 3/22/57 N45E	45.90	1.76	0.195	64.209		4.855	1.78	.211	7.222	
	3/22/57 N45W)	44.90	1.76	0.235		.98	5.347	2.68	.196		.93
20	San Francisco 3/22/57 Vert	26.30	2.78	0.290	49.653		2.978	.84	.259	4.299	
	3/22/57 S09W	41.80	2.68	0.186		.89	3.10	2.80	.235		.83
21	San Francisco 3/22/57 N81E	45.40	2.04	0.158	54.416		2.707	3.12	.267	4.632	
	3/22/57 Vert.	30.00	0.14	0.207		.95	3.759	.36	.215		.78
22	San Francisco 3/22/57 N10E	81.80	1.34	0.131	131.374		11.97	1.94	.177	18.42	
	3/22/57 S80E	102.80	1.44	0.139		.97	14.01	1.66	.135		.96
23	San Francisco 3/22/57 Vert	37.20	1.18	0.125	91.686		4.793	1.52	.167	11.61	
	3/22/57 S09E	63.80	1.80	0.171		.94	10.57	1.82	.134		.97
24	San Francisco 3/22/57 S81W	55.10	2.12	0.201	70.202		7.496	1.24	.154	8.81	
	3/22/57 Vert	43.50	1.62	0.170		.95	4.625	1.42	.209		.93

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TABLE 8 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
25	San Francisco 3/22/57 (N26E)	39.00	0.48	.159	45.636		4.873	1.02	.176	6.69	
	3/22/57 (S64E)	23.70	1.26	.201		.91	4.589	2.00	.231		.91
26	San Francisco 3/22/57 (Vert)	15.30	0.34	.201	65.220		1.924	2.62	.234	7.85	
	Hollister 4/8/61 (S01W)	63.40	1.04	.343		.92	7.61	2.00	.225		.84
27	Hollister 4/8/61 (N89W)	175.70	1.20	.181	182.431		13.66	1.54	.103	14.138	
	4/8/61 (N89W)	49.10	1.28	.214		.76	3.64	1.62	.234		.78
28	Borrego Mount. 4/8/68 (S00W)	127.80	8.54	.184	139.651		10.27	7.52	.224	11.25	
	4/8/68 (S90W)	56.30	15.00	.313		.89	4.59	5.26	.314		.83
29	Borrego Mount. 4/6/68 (Vert)	29.70	7.56	.269	41.861		3.86	13.32	.288	4.44	
	4/6/68 (S00W)	29.50	8.54	.236		.89	2.196	9.54	.241		.85
30	Borrego Mount. 4/8/68 (N90E)	28.90	8.62	.264	31.567		1.744	7.54	.332	2.05	
	4/8/68 (Vert)	12.70	10.90	.278		.90	1.079	7.88	.299		.69
31	Long Beach 3/10/33 (S08W)	130.60	1.88	.226	200.021		11.65	1.02	.25	15.07	
	3/10/33 (N82W)	151.50	2.14	.174		.97	9.55	1.86	.21		.93
32	Long Beach 3/10/33 (N82W)	149.50	1.00	.109	155.644		11.36	1.18	.20	11.71	
	Southern Cal. 10/2/33	43.30	0.20	.281		.97	2.85	.70	.24		.94

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TABLE 8 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
33	Southern Cal. 10/2/33 (N90E)	85.40	0.22	0.343	89.506		5.03	.20	.29	5.68	
	10/2/33 (DOWN)	26.80	0.22	0.271		.92	2.64	.72	.29		.71
34	Southern Cal. 10/2/33 (N00E)	32.10	0.12	0.184	41.561		2.55	.14	.18	3.85	
	10/2/33 (N90W)	26.40	0.28	0.234		.92	2.87	.32	.15		.99
35	Southern Cal. 10/2/33 (DOWN)	10.70	2.34	0.359	157.165		1.42	.86	.19	15.89	
	Lower Cal. 12/30/34 (S00W)	156.80	3.32	0.280		.89	15.83	7.76	.324		.80
36	Lower Cal. 12/30/34 (S90W)	179.10	15.12	0.220	191.61		16.65	2.14	.236	18.80	
	12/30/34 (Vert)	68.10	3.40	0.268		.86	8.74	2.78	.272		.83
37	Helena, Montana 10/31/35 (S00W)	143.50	3.04	0.121	202.234		19.397	3.14	.18	23.34	
	10/31/35 (S90W)	142.50	2.42	0.154		.96	12.97	2.54	.17		.95
38	Helena, Montana 10/31/35 (DOWN)	87.50	2.32	0.146	165.858		8.84	3.00	.21	16.498	
	9/11/38 (N45E)	140.90	2.26	0.143		.99	13.93	2.28	.215		.95

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TABLE 9 EARTHQUAKE COMBINATION (15 sec duration) in Z-direction
9 DEGREES OF FREEDOM

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
1	Imperial Valley 5/18/40 (S00E)	341.70	2.12	0.227	401.124		34.459	5.46	.269	41.583	
	5/18/40 (S90N)	210.10	11.44	0.253		.88	22.516	5.80	.299		.69
2	Imperial Valley 5/18/40 (Vert.)	206.30	0.98	0.207	230.138		34.741	1.38	.199	37.979	
	N.W. California 10/7/51 (S44N)	102.00	4.14	0.182		.88	14.815	4.12	.191		.89
3	N.W. California 10/7/51 (N46W)	109.50	4.38	0.190	112.637		13.377	4.36	.227	13.665	
	10/7/51 (Vert.)	26.40	3.00	0.302		.90	2.693	6.16	.291		.69
4	Kern County Cal. 7/21/52 (S00E)	46.50	17.34	0.268	69.833		3.292	7.48	.279	5.141	
	7/21/52 (S90W)	52.10	16.70	0.335		.86	3.949	7.90	.297		.84
5	Kern County Cal. 7/21/52 (Vert.)	29.30	19.32	0.328	155.485		2.918	4.30	.219	18.49	
	7/21/52 (N21E)	152.70	9.10	0.276		.76	18.26	8.20	.313		.78
6	Kern County Cal. 7/21/52 (S69E)	175.90	3.70	0.250	203.787		21.783	6.52	.268	26.14	
	7/21/52 (Vert)	102.90	9.76	0.265		.87	14.45	6.18	.286		.79
7	Kern County Cal 7/21/52 (N42E)	87.80	11.58	0.308	155.714		5.333	4.64	.354	9.53	
	7/21/52 (S48E)	128.60	6.98	0.219		.93	7.89	6.96	.237		.78
8	Kern County Cal. 7/21/52 (Vert.)	43.60	8.12	0.293	69.482		10.39	8.14	.236	11.51	
	7/21/52 (S00N)	54.10	13.28	0.285		.85	4.95	8.10	.281		.85

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TABLE 9 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
9	Kern County Cal. 7/21/52 (N90E)	43.50	12.92	0.322	48.974		3.176	7.52	.327	3.76	
	7/21/52 (Vert)	22.50	21.98	0.269		.79	2.006	1.06	.293		.56
10	Kern County Cal. 7/21/52 (S00W)	58.10	13.30	0.270	71.225		7.15	8.10	.243	8.50	
	7/21/52 (N90E)	41.20	12.98	0.342		.91	4.60	9.14	.266		.85
11	Kern County Cal. 7/21/52 (Vert)	20.30	18.06	0.317	165.748		3.214	4.92	.259	18.04	
	Eureka 12/21/54 (N11W)	164.50	4.84	0.222		.72	17.752	3.82	.20		.74
12	Eureka 12/21/54 (N79E)	252.70	3.84	0.210	265.456		29.436	3.84	.183	30.889	
	12/21/54 (Vert)	81.30	0.16	0.196		.88	9.36	.18	.268		.86
13	Eureka 12/21/54 (N44E)	155.70	6.88	0.271	251.336		15.49	7.18	.196	26.17	
	12/21/54 (N46W)	197.30	7.10	0.186		.97	21.096	7.12	.144		.97
14	Eureka 12/21/54 (Vert)	41.90	8.00	0.306	108.608		3.029	7.46	.319	10.254	
	9/4/55 (N31W)	100.20	1.20	0.173		.61	9.796	1.22	.181		.46
15	San Jose 9/4/55 (N59E)	105.80	1.20	0.139	114.66		13.076	1.20	.167	14.84	
	9/4/55 (Vert)	44.20	1.58	0.150		.97	7.027	1.66	.158		.95
16	El Alamo Cal. 2/9/56 (S00W)	32.40	10.16	0.362	59.664		4.167	2.42	.317	6.149	
	2/9/56 (S90W)	50.10	6.80	0.314		.68	4.52	10.40	.290		.72

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TABLE 9 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
17	El Alamo Cal. 2/9/56 Vert.	12.40	9.48	0.317	17.117		2.104	3.28	.347	2.34	
	2/9/56 S00W	11.80	1.10	0.255		.68	1.017	4.74	.306		.69
18	El Alamo Cal 2/9/56 S90W	15.40	0.66	0.267	15.749		1.41	2.00	.23	1.51	
	2/9/56 Vert	3.30	0.00	0.305		.96	.532	4.14	.273		.69
19	San Francisco 3/22/57 N45E	45.90	1.76	0.195	64.509		6.004	1.76	.193	8.62	
	3/22/57 N45W	44.90	1.76	0.235		.98	6.185	2.68	.194		.94
20	San Francisco 3/22/57 Vert	26.30	2.78	0.240	49.653		4.355	1.92	.203	6.23	
	3/22/57 S09W	41.80	2.68	0.186		.89	4.449	2.70	.202		.93
21	San Francisco 3/22/57 N81E	45.40	2.04	0.158	54.416		3.48	2.06	.239	5.786	
	3/22/57 Vert.	30.00	0.14	0.207		.95	4.62	.36	.20		.85
22	San Francisco 3/22/57 N10E	81.80	1.34	0.131	131.374		13.68	1.94	.16	21.14	
	3/22/57 S80E	102.80	1.44	0.139		.97	16.12	1.66	.13		.97
23	San Francisco 3/22/57 Vert	37.20	1.18	0.125	91.636		5.894	1.44	.148	14.274	
	3/22/57 S09E	63.80	1.80	0.171		.94	13.00	1.82	.131		.96
24	San Francisco 3/22/57 S81W	55.10	2.12	0.201	70.202		8.96	1.24	.152	10.48	
	3/22/57 Vert	43.50	1.62	0.170		.95	5.44	1.32	.198		.93

-11-

BEST DOCUMENT AVAILABLE

TABLE 9 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
25	San Francisco 3/22/57 (N26E)	39.00	0.48	.159	45.636		5.755	1.02	.166	7.47	
	3/22/57 (S64E)	23.70	1.26	.201		.91	4.762	2.00	.229		.90
26	San Francisco 3/22/57 (Vert)	15.30	0.34	.201	65.220		2.308	2.00	.218	8.98	
	Hollister 4/8/61 (S01W)	63.40	1.04	.348		.92	8.68	2.00	.232		.87
27	Hollister 4/8/61 (N89W)	175.70	1.20	.181	182.431		15.729	1.22	.174	16.26	
	4/8/61 (N89W)	49.10	1.28	.214		.76	4.13	1.62	.242		.65
28	Borrego Mount. 4/8/68 (S00W)	127.80	8.54	.184	139.651		13.463	7.52	.193	14.47	
	4/8/68 (S90W)	56.30	15.00	.313		.89	5.31	2.46	.32		.84
29	Borrego Mount. 4/6/68 (Vert)	29.70	7.56	.269	41.861		3.99	7.40	.33	4.64	
	4/6/68 (S00W)	29.50	8.54	.236		.89	2.37	8.84	.27		.72
30	Borrego Mount 4/8/68 (N90E)	28.90	8.62	.264	31.567		2.325	7.54	.301	2.59	
	4/8/68 (Vert)	12.70	10.90	.278		.90	1.15	7.88	.322		.74
31	Long Beach 3/10/33 (S08W)	130.60	1.88	.226	200.021		14.462	1.02	.234	19.78	
	3/10/33 (N82W)	151.50	2.14	.174		.97	13.50	1.84	.181		.96
32	Long Beach 3/10/33 (N82W)	149.50	1.00	.109	155.644		12.64	1.64	.201	13.15	
	Southern Cal. 10/2/33 (N00E)	43.30	0.20	.281		.97	3.63	.70	.251		.92

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TABLE 9 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
33	Southern Cal. 10/2/33 (N90E)	85.40	0.22	0.343	89.506		6.26	1.10	.324	6.96	
	10/2/33 (DOWN)	26.80	0.22	0.271		.92	3.04	0.72	.284		.90
34	Southern Cal. 10/2/33 (N00E)	32.10	0.12	0.184	41.561		2.93	.14	.187	4.60	
	10/2/33 (N90W)	26.40	0.28	0.234		.92	3.55	.32	.154		.99
35	Southern Cal. 10/2/33 (DOWN)	10.70	2.34	0.359	157.165		1.604	.86	.206	20.66	
	Lower Cal. 12/30/34 (S00W)	156.80	3.32	0.280		.89	20.60	7.76	.282		.77
36	Lower Cal. 12/30/34 (S90W)	179.10	15.12	0.220	191.61		20.417	2.12	.227	22.95	
	12/30/34 (Vert)	68.10	3.40	0.268		.86	10.49	2.78	.275		.79
37	Helena, Montana 10/31/35 (S00W)	143.50	3.04	0.121	202.234		17.93	2.92	.197	22.12	
	10/31/35 (S90W)	142.50	2.42	0.154		.96	12.94	2.52	.196		.91
38	Helena, Montana 10/31/35 (DOWN)	87.50	2.32	0.146	165.858		12.68	2.98	.163	21.63	
	N.W. California 9/11/36 (N45E)	140.90	2.26	0.143		.99	17.53	2.28	.19		.97

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TABLE 10 EARTHQUAKE COMBINATION (15 sec duration) in X-direction
30 DEGREES OF FREEDOM

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
1	Imperial Valley 5/18/40 (S00E)	341.70	2.12	0.227	401.124		16.299	5.0	.238	17.94	
	5/18/40 (S90N)	210.10	11.44	0.253		.88	7.487	.24	.292		.86
2	Imperial Valley 5/18/40 (Vert.)	206.30	0.98	0.207	230.138		30.65	1.32	.184	30.96	
	N.W. California 10/7/51 (S44N)	102.00	4.14	0.182		.88	4.36	4.14	.222		.72
3	N.W. California 10/7/51 (N46W)	109.50	4.38	0.190	112.637		4.42	4.36	.223	4.597	
	10/7/51 (Vert.)	26.40	3.00	0.302		.90	1.25	3.02	.227		.89
4	Kern County Cal. 7/21/52 (S00E)	46.50	17.34	0.268	69.833		1.245	7.54	.236	1.72	
	7/21/52 (S90W)	52.10	16.70	0.335		.86	1.19	7.48	.31		.92
5	Kern County Cal. 7/21/52 (Vert.)	29.30	19.32	0.328	155.485		.995	8.54	.33	7.095	
	7/21/52 (N21E)	152.70	9.10	0.276		.76	7.03	8.2	.25		.76
6	Kern County Cal. 7/21/52 (S69E)	175.90	3.70	0.250	203.787		7.645	8.54	.235	9.82	
	7/21/52 (Vert.)	102.90	9.76	0.265		.87	6.16	2.96	.286		.85
7	Kern County Cal. 7/21/52 (N42E)	87.80	11.58	0.308	155.714		1.92	7.50	.313	3.25	
	7/21/52 (S48E)	128.60	6.98	0.219		.93	2.63	6.98	.224		.88
8	Kern County Cal. 7/21/52 (Vert.)	43.60	8.12	0.293	69.482		2.865	8.96	.211	3.23	
	7/21/52 (S00N)	54.10	13.28	0.285		.85	1.497	8.12	.264		.85

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TABLE 10 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
9	Kern County Cal. 7/21/52 (N90E)	43.50	12.92	0.322	48.974		1.051	7.52	.307	1.19	
	7/21/52 (Vert.)	22.50	21.98	0.269		.79	.559	1.08	.311		.54
10	Kern County Cal. 7/21/52 (S00W)	58.10	13.30	0.270	71.225		1.817	7.44	.276	2.31	
	7/21/52 (N90E)	41.20	12.98	0.342		.91	1.432	9.50	.279		.74
11	Kern County Cal 7/21/52 (Vert)	20.30	18.06	0.317	165.748		.997	5.48	.282	5.37	
	Eureka 12/21/54 (N11W)	164.50	4.84	0.222		.72	5.27	6.46	.235		.75
12	Eureka 12/21/54 (N79E)	252.70	3.84	0.210	265.456		7.715	5.80	.217	9.52	
	12/21/54 (Vert)	91.30	0.16	0.196		.88	5.576	.98	.223		.80
13	Eureka 12/21/54 (N44E)	155.70	6.88	0.271	251.336		5.141	7.92	.201	6.71	
	12/21/54 (N46W)	197.30	7.10	0.186		.97	4.315	7.14	.217		.94
14	Eureka 12/21/54 (Vert)	41.90	8.00	0.306	108.608		1.21	6.54	.312	3.27	
	9/4/55 (N31W)	100.20	1.20	0.173		.61	3.04	.94	.166		.70
15	San Jose 9/4/55 (N59E)	105.80	1.20	0.139	114.66		4.12	1.20	.145	5.156	
	9/4/55 (Vert)	44.20	1.58	0.150		.97	3.099	1.66	.157		.97
16	El Alamo Cal. 2/9/56 (S00W)	32.40	10.16	0.362	59.664		1.46	2.98	.292	2.021	
	2/9/56 (S90W)	50.10	6.80	0.314		.60	1.397	11.34	.30		.66

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TABLE 10 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
17	El Alamo Cal. 2/9/56 Vert	12.40	9.48	0.317	17.117		.936	6.60	.302	.987	
	2/9/56 S00W	11.80	1.10	0.255		.68	.314	5.76	.283		.74
18	El Alamo Cal. 2/9/56 S90W	15.40	0.66	0.267	15.749		.410	2.08	.248	.45	
	2/9/56 Vert	3.30	0.00	0.305		.96	.183	5.48	.270		.71
19	San Francisco 3/22/57 N45E	45.90	1.76	0.195	64.209		1.557	1.76	.213	2.15	
	3/22/57 N45W	44.90	1.76	0.235		.98	1.488	1.74	.234		.92
20	San Francisco 3/22/57 Vert	26.30	2.78	0.230	49.653		2.22	1.86	.181	3.53	
	3/22/57 S09W	41.80	2.68	0.186		.89	2.74	2.54	.148		.95
21	San Francisco 3/22/57 N81E	45.40	2.04	0.158	54.416		1.419	2.62	.218	2.12	
	3/22/57 Vert.	30.00	0.14	0.207		.95	1.572	1.92	.229		.90
22	San Francisco 3/22/57 N10E	81.80	1.34	0.131	131.374		4.586	2.58	.17	7.87	
	3/22/57 S80E	102.80	1.44	0.139		.97	6.398	1.84	.172		.94
23	San Francisco 3/22/57 Vert	37.20	1.18	0.125	91.686		2.282	1.64	.181	5.14	
	3/22/57 S09E	63.80	1.80	0.171		.94	4.606	1.94	.162		.94
24	San Francisco 3/22/57 S81W	55.10	2.12	0.201	70.202		3.182	2.49	.169	3.82	
	3/22/57 Vert.	43.50	1.62	0.170		.95	2.121	2.08	.182		.95

82

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TABLE 10 (CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
25	San Francisco 3/22/57 (N26E)	39.00	0.48	.159	49.636		1.596	.58	.190	2.163	
	3/22/57 (S64E)	23.70	1.26	.201		.91	1.459	2.72	.201		.88
26	San Francisco 3/22/57 (Vert)	15.30	0.34	.201	65.220		1.18	1.98	.200	2.99	
	Hollister 4/8/61 (S01W)	63.40	1.04	.348		.92	2.30	2.44	.275		.90
27	Hollister 4/8/61 (N89W)	175.70	1.20	.181	182.431		4.79	1.20	.169	4.95	
	4/8/61 (N89W)	49.10	1.28	.214		.76	1.25	1.32	.259		.73
28	Borrego Mount. 4/8/68 (S00W)	127.80	8.54	.184	139.651		4.187	7.52	.181	4.634	
	4/8/68 (S90W)	56.30	15.00	.313		.89	1.98	4.96	.289		.88
29	Borrego Mount. 4/6/68 (Vert)	29.70	7.56	.269	41.861		2.279	8.18	.288	2.49	
	4/6/68 (S00W)	29.50	8.54	.236		.89	1.01	8.84	.208		.86
30	Borrego Mount. 4/8/68 (N90E)	28.90	8.62	.264	31.567		1.047	9.16	.227	1.18	
	4/8/68 (Vert)	12.70	10.90	.278		.90	.535	8.50	.266		.82
31	Long Beach 3/10/33 (S08W)	130.60	1.88	.226	200.021		6.79	1.20	.215	8.415	
	3/10/33 (N82W)	151.50	2.14	.174		.97	4.97	1.74	.190		.91
32	Long Beach 3/10/33 (N82W)	149.50	1.00	.109	155.644		5.67	1.90	.204	5.82	
	Southern Cal. 10/2/33 (N00E)	43.40	0.20	.281		.97	1.31	.18	.222		.94

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TABLE 10(CONTINUE) EARTHQUAKE COMBINATION (15 sec duration)

Set No.	Components	Load Level					Response Level				
		Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS	Peak Value	at time	σ/R_{max}	SRSS	NEP of SRSS
33	Southern Cal. 10/2/33 (N90E)	85.40	0.22	0.343	89.506		2.533	.24	.260	2.80	
	10/2/33 (OWN)	26.80	0.22	0.271		.92	1.18	.90	.254		.80
34	Southern Cal. 10/2/33 (N00E)	32.10	0.12	0.184	41.561		.945	.10	.187	1.31	
	10/2/33 (N90W)	26.40	0.28	0.234		.92	.904	.06	.198		.97
35	Southern Cal. 10/2/33 (OWN)	10.70	2.34	0.359	157.165		.509	.88	.213	8.03	
	Lower Cal. 12/30/34 (S00W)	156.80	3.32	0.280		.89	8.01	4.36	.264		.86
36	Lower Cal. 12/30/34 (S90W)	179.10	15.12	0.220	191.61		9.78	2.62	.187	11.55	
	12/30/34 (Vert)	68.10	3.40	0.268		.86	6.14	1.3	.275		.94
37	Helena, Montana 10/31/35 (S00W)	143.50	3.04	0.121	202.234		8.18	3.26	.168	9.74	
	10/31/35 (S90W)	142.50	2.42	0.154		.96	5.28	2.66	.174		.92
38	Helena, Montana 10/31/35 (OWN)	87.50	2.32	0.146	165.858		5.75	2.78	.172	7.55	
	N.W. California 9/11/38 (N45E)	140.90	2.26	0.143		.99	4.9	2.78	.194		.97

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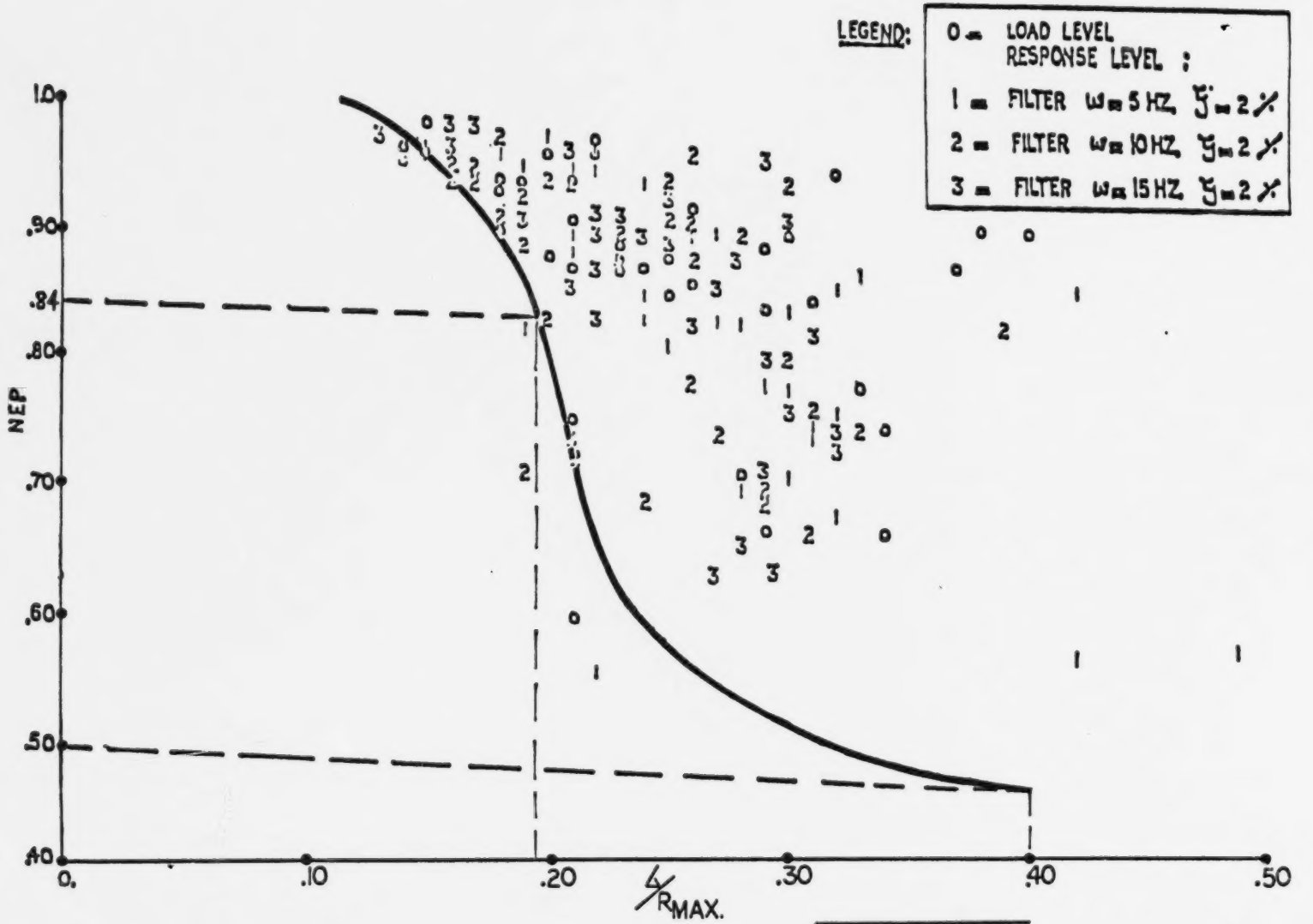

FIG.11 EARTHQUAKE ON S.D.O.F. SYSTEMS $\Delta/R_{MAX.} = \frac{1}{\sqrt{2}}\sqrt{A_1\left(\frac{\Delta_1}{R_{1m}}\right)^2 + A_2\left(\frac{\Delta_2}{R_{2m}}\right)^2}$ WHERE $A_1 = \left(\frac{R_{1m}}{R_{av.}}\right)^2, A_2 = \left(\frac{R_{2m}}{R_{av.}}\right)^2$

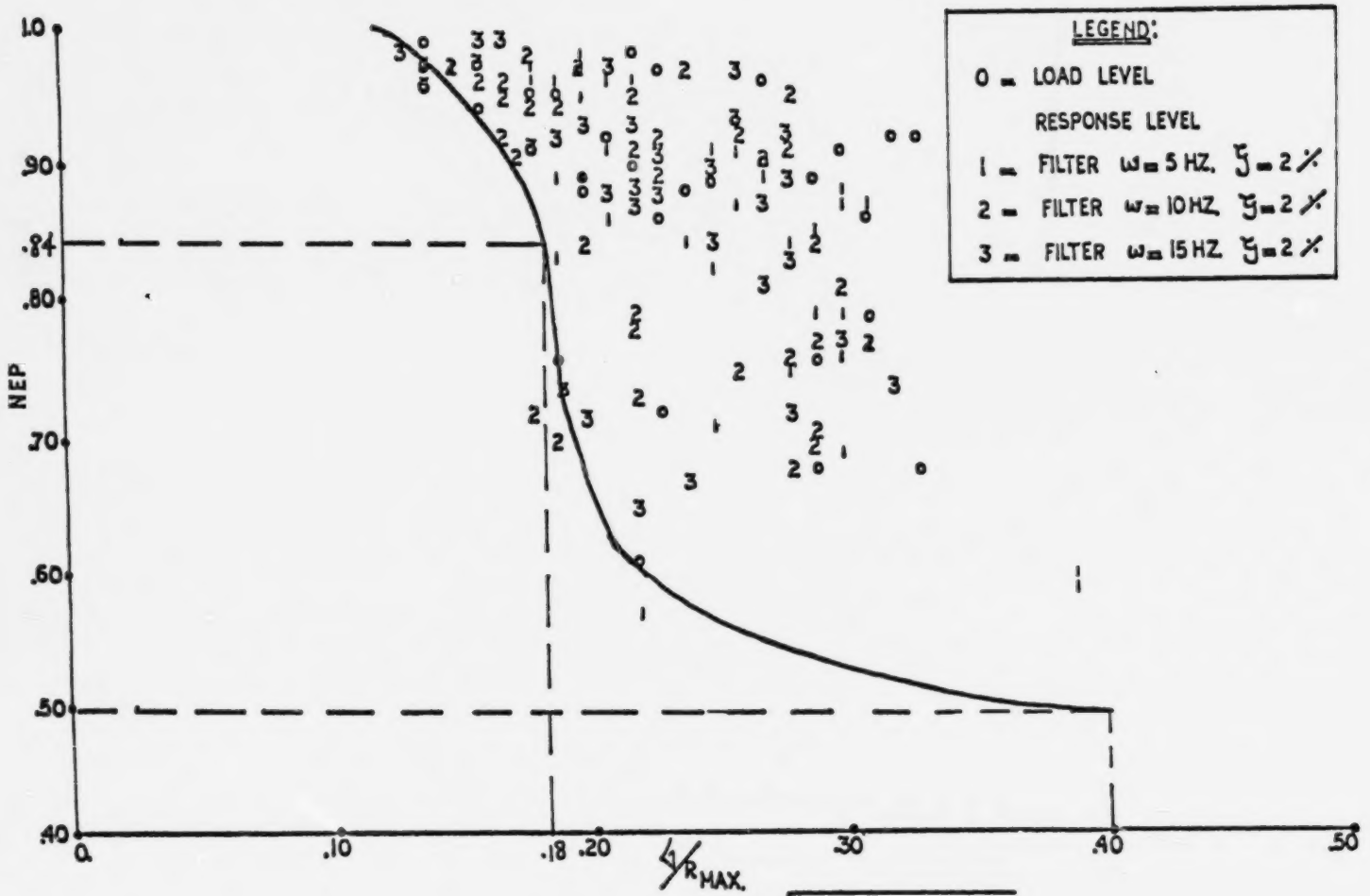

FIG. 12 EARTHQUAKE ON S.D.O.F. SYSTEMS $y/R_{MAX.} = \frac{1}{\sqrt{2}}\sqrt{A_1\left(\frac{y_{1i}}{R_{1m}}\right)^2 + A_2\left(\frac{y_{2i}}{R_{2m}}\right)^2}$

WHERE $A_1 = \left(\frac{R_{1m}}{R_{av.}}\right)$, $A_2 = \left(\frac{R_{2m}}{R_{av.}}\right)$

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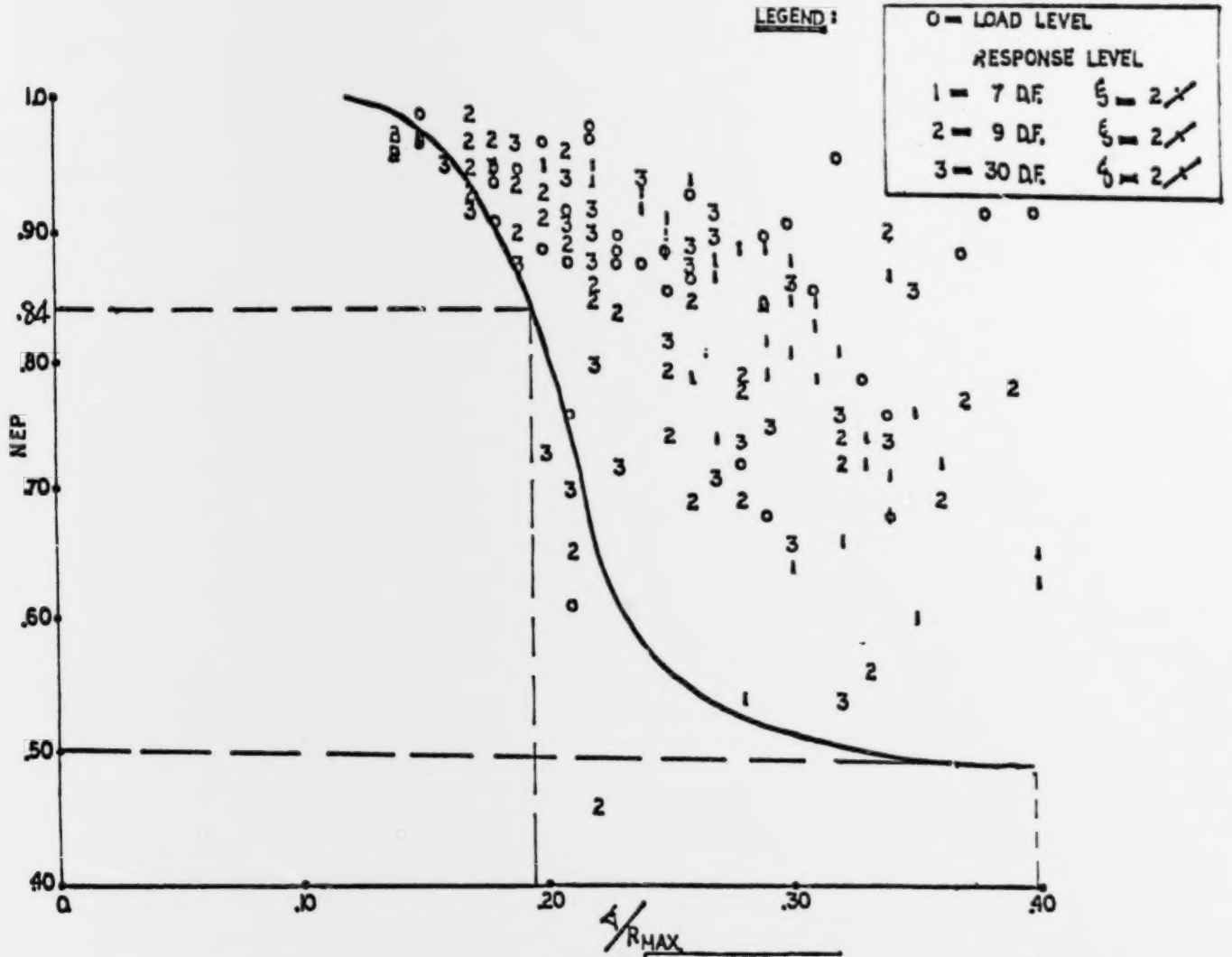

FIG. 13 EARTHQUAKE ON M.D.O.F. SYSTEM $\frac{\Delta}{R_{MAX.}} = \frac{1}{\sqrt{2}}\sqrt{A\left(\frac{\Delta_1}{R_{1m}}\right)^2 + A_2\left(\frac{\Delta_{12}}{R_{2m}}\right)^2}$ WHERE $A_1 = \left(\frac{R_{1m}}{R_{av.}}\right)^2$, $A_2 = \left(\frac{R_{2m}}{R_{av.}}\right)^2$

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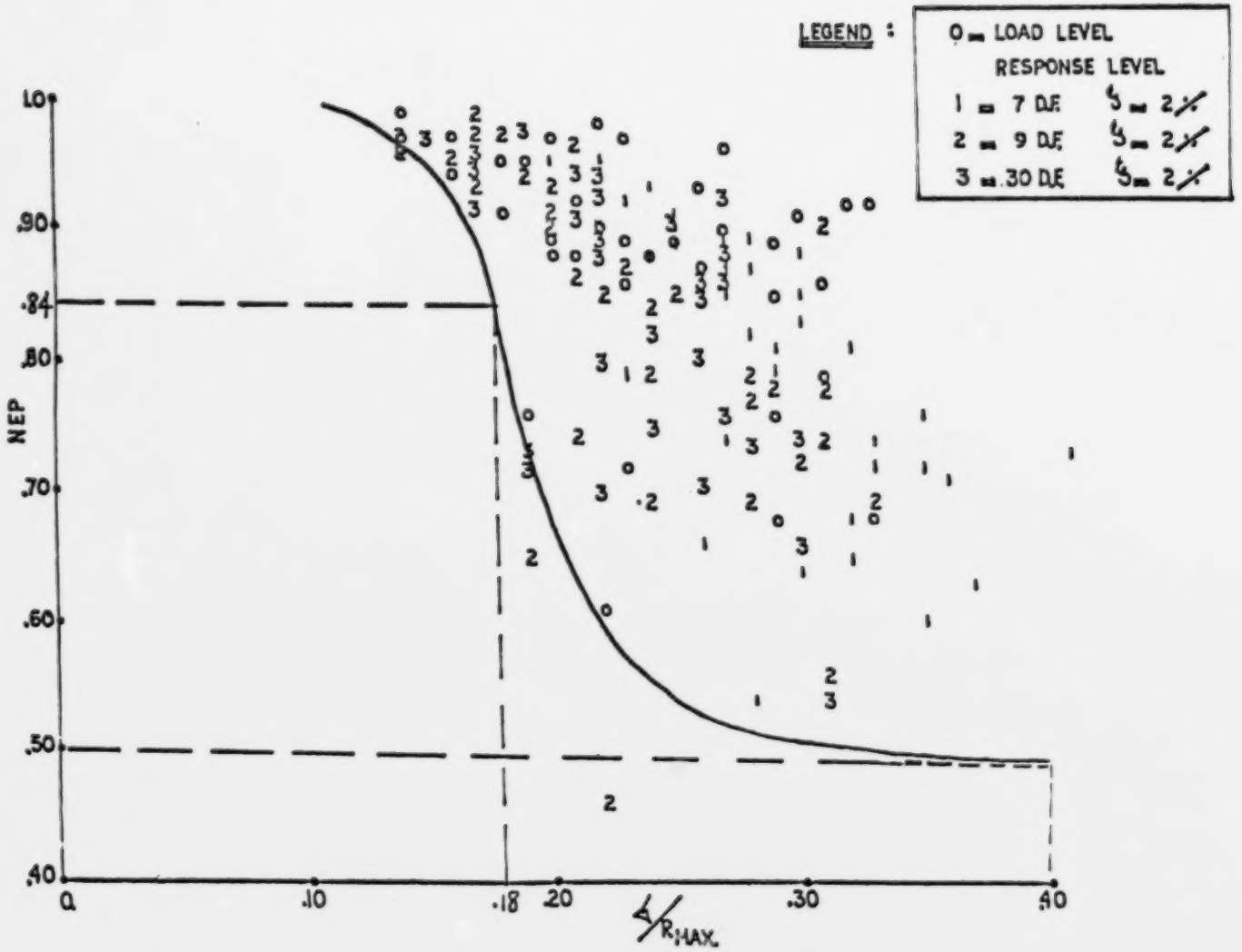

FIG. 14 EARTHQUAKE ON M.D.O.F. SYSTEM $\frac{\Delta}{R_{MAX.}\sqrt{2}} = \sqrt{A_1\left(\frac{\Delta_{1L}}{R_{1m}}\right)^2 + A_2\left(\frac{\Delta_{12}}{R_{2m}}\right)^2}$ WHERE $A_1 = \frac{R_{1m}}{R_{av.}}$, $A_2 = \frac{R_{2m}}{R_{av.}}$

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4.0 VERIFICATION OF MODIFIED KENNEDY-NEWMARK CRITERION 1

The modified Kennedy-Newmark criterion 1 (see Appendix) can be summarized as follows:

1) For each response time history

$$\frac{T_{75}}{\Delta T} \text{ and } \frac{T_{-75}}{\Delta T} \leq 0.02 \tag{26}$$

and

$$\frac{T_{50}}{\Delta T} \text{ and } \frac{T_{-50}}{\Delta T} \leq 0.08 \tag{27}$$

2) For each input time history

$$\frac{T_{75}}{\Delta T} \text{ and } \frac{T_{-75}}{\Delta T} \leq 0.01 \tag{28}$$

and

$$\frac{T_{50}}{\Delta T} \text{ and } \frac{T_{-50}}{\Delta T} \leq 0.04 \tag{29}$$

In the above equations, ΔT is the time interval over which the lag time between responses is considered random, and T_{50} and T_{75} are the lengths of time where the waveform exceeds 50% and 75% of the maximum value.

3) For the cases where each input or response does not satisfy conditions 1 and 2, a modified effective ratio is calculated using the following formula:

$$\left(\frac{T_{75}}{\Delta T}\right)_e = \sqrt{\left(\sum_{i=1}^{N} (R_m T_{75}/\Delta T)_i^2\right) \Big/ \sum_{i=1}^{N} (R_m)_i^2} \tag{30}$$

in the above equation, i represents each individual response in the combination

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and $(R_m)_i$ represents the maximum response of the i-th response component. The effective time ratio $(T_{50}/\Delta T)_e$ is obtained by substituting 50 for 75 in Equation 30.

To verify this modified criterion, a number of responses both from the G. E. report and using real earthquake time-histories were utilized. The results of the G. E. responses are summarized in Tables 11 and 12. They consist of 64 combinations given in Table G-7 of Reference 6. Of these 64 cases, 26 satisfied both requirements of the Kennedy-Newmark modified criterion. One of these 26 cases, however, had an NEP of SRSS < .5. There were 33 cases which failed both requirements of the Kennedy-Newmark modified criterion. However, 6 of these cases have an NEP of SRSS greater than 0.8. Of the remaining 5 cases which failed one of the two requirements of the Kennedy-Newmark criterion, the NEP of SRSS valus of 3 were above 90%. Thus, for the cases investigated, the criterion ruled out cases that normally should have been accepted, and accepted one case that normally should have been rejected.

For real earthquakes, the verification of the modified Kennedy-Newmark criterion 1 is summarized in Tables 13-18. The first 3 tables give effective $T_{50}/\Delta T$, $T_{75}/\Delta T$, $T_{-75}/\Delta T$, and $T_{-50}/\Delta T$ values for the earthquake responses of the single-degree-of-freedom systems with natural frequencies of 5, 10, and 15 Hz. The remaining tables summarize those data for the earthquake responses of the multi-degree-of-freedom system by taking the first 7, 9, and 30 modes. Of the more than 200 cases of earthquake responses, only 12 cases reveal that the modified Kennedy-Newmark criterion 1 does not apply. It appears that the modified Kennedy-Newmark criterion 1 applies to earthquake type responses alone quite well. The correctness of this method regarding the other dynamic responses are however, questionable as discussed in the previous paragraph.

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Table 11 R.P.V. and Internal Response 1 of 3

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
1	1	[illegible]	.01	.030	.05	.040	.0[illegible]	.040	.05	.059	.62
	6	[illegible]07	.03		.04		.0[illegible]		.09		
2	[illegible]	61	.01	.029	.05	.041	.00	.038	.03	.057	.57
	6	[illegible]07	.03		.04		.04		.03		
3	1	[illegible]1.7	.01	.050	.0[illegible]	.089	.00	.010	.0[illegible]	.0[illegible]	.1[illegible]
	[illegible]	[illegible]38	.05		.0[illegible]		.01		.0[illegible]		
4	[illegible]	[illegible]	.01	.048	.05	.033	.00	.010	.03	.0[illegible]	.69
	[illegible]	[illegible]3[illegible]	.05		.0[illegible]		.01		.07		
5	[illegible]	[illegible]1.[illegible]	.00	.039	.03	.059	.01	.030	.05	.0[illegible]	.[illegible]4
	[illegible]	[illegible]2[illegible]	.04		.0[illegible]		.0[illegible]		.10		
6	[illegible]	[illegible]1.[illegible]	.00	.030	.03	.109	.01	.059	.06	.109	.33
	11	1[illegible].7	.03		.11		.10		.11		
7	5	62.9	.00	.038	.03	.086	.01	.029	.05	.059	.45
	[illegible]	1[illegible]5	.04		.0[illegible]		.03		.06		
8	5	62.9	.00	.029	.03	.105	.01	.057	.05	.106	.38
	11	199	.03		.11		.06		.11		
9	1[illegible]	327	.01	.029	.05	.048	.00	.032	.03	.077	.64
	[illegible]	2[illegible]1	.03		.0[illegible]		.04		.08		
10	[illegible]	327	.01	.047	.05	.115	.00	.090	.03	.025	.65
	13	944	.05		.12		.07		.10		
11	[illegible]	5.1	.01	.011	.03	.030	.01	.015	.07	.071	.95
	[illegible]	1.5	.02		.0[illegible]		.04		.[illegible]		
12	[illegible]	255	.01	.011	.0[illegible]	.071	.01	.015	.07	.071	.92
	25	80.3	.02		.0[illegible]		.04		.[illegible]		

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No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T-75}{\Delta T}$	$\left(\frac{T-75}{\Delta T}\right)_{MOD}$	$\frac{T-50}{\Delta T}$	$\left(\frac{T-50}{\Delta T}\right)_{MOD}$	NEP OF SRSS
13	18	10.2	.01	.010	.07	.070	.01	.011	.07	.070	.94
	24	1.5	.02		.08		.04		.08		
14	19	537	.01	.010	.08	.080	.01	.012	.07	.070	.95
	25	80.3	.02		.08		.04		.08		
15	17	5.1	.01	.021	.09	.078	.01	.008	.07	.099	.91
	30	4.3	.03		.07		.00		.11		
16	13	263	.01	.033	.05	.070	.01	.015	.07	.099	.94
	31	22.4	.05		.07		.02		.11		
17	15	12.2	.01	.015	.07	.070	.01	.009	.07	.077	.93
	29	4.3	.03		.07		.00		.11		
18	17	537	.01	.021	.08	.079	.01	.012	.07	.077	.95
	21	226	.05		.07		.02		.11		
19	14	166	.01	.013	.06	.062	.01	.013	.06	.061	.95
	26	16.6	.08		.16		.08		.12		
20	15	33700	.01	.013	.06	.063	.01	.013	.06	.061	.95
	27	3300	.06		.22		.03		.12		
21	20	332	.01	.011	.06	.061	.01	.011	.06	.060	.96
	26	16.6	.08		.10		.05		.12		
22	21	77500	.01	.011	.06	.061	.01	.011	.06	.060	.95
	27	3800	.05		.22		.05		.12		
23	14	166	.01	.011	.06	.072	.01	.017	.06	.072	.95
	32	47	.02		.16		.05		.16		
24	15	38700	.01	.021	.06	.079	.01	.023	.06	.067	.96
	33	10700	.07		.20		.08		.13		

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No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
25	20	3332	.01	.010	.06	.063	.01	.012	.06	.063	.96
	32	47	.02		.16		.05		.16		
26	21	77500	.01	.014	.06	.059	.01	.015	.01	.062	.95
	33	10703	.07		.20		.08		.13		
27	16	48.2	.01	.017	.07	.079	.01	.024	.03	.090	.91
	28	15.9	.04		.12		.06		.14		
28	17	70500	.01	.010	.06	.060	.01	.010	.05	.051	.95
	29	7070	.02		.08		.02		.10		
29	22	96.7	.01	.012	.07	.072	.01	.015	.07	.074	.96
	28	15.9	.04		.12		.06		.14		
30	23	141000	.01	.010	.06	.060	.00	.001	.04	.040	.95
	29	7070	.02		.08		.02		.10		
31	16	48.2	.01	.018	.07	.070	.01	.018	.03	.080	.76
	34	78.7	.02		.07		.02		.08		
32	17	70500	.01	.027	.06	.078	.01	.013	.05	.071	.95
	35	21600	.07		.18		.03		.18		
33	22	96.7	.01	.015	.07	.070	.01	.015	.07	.074	.88
	34	78.7	.02		.07		.02		.08		
34	23	141000	.01	.014	.06	.065	.00	.005	.04	.048	.99
	35	21600	.07		.15		.03		.13		

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Table 12 Combination of Moment A, B, C

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
35	42	2030	.00	.019	.07	.095	.01	.019	.05	.097	.60
	36	7190	.02		.10		.02		.10		
36	42	2030	.00	.018	.07	.087	.01	.010	.05	.093	.64
	37	4200	.02		.09		.01		.10		
37	63	19900	.00	.015	.07	.092	.01	.010	.05	.058	.89
	45	03500	.02		.04		.01		.04		
38	63	19900	.00	.005	.05	.054	.01	.006	.05	.044	.93
	46	4500	.01		.03		.03		.04		
39	66	29600	.02	.025	.14	.167	.02	.025	.15	.149	.57
	51	7820	.06		.17		.06		.17		
40	66	29800	.02	.059	.17	.165	.02	.028	.15	.144	.79
	52	20300	.10		.21		.04		.13		
41	69	4160	.01	.105	.05	.200	.01	.114	.06	.229	.51
	57	12100	.11		.21		.12		.24		
42	69	4160	.01	.079	.05	.238	.01	.001	.06	.119	.54
	58	31400	.08		.24		.00		.12		
43	81	61100	.01	.057	.05	.161	.00	.066	.07	.171	.60
	75	179000	.06		.17		.07		.18		
44	78	4340	.01	.019	.04	.068	.01	.010	.04	.068	.73
	72	14100	.02		.07		.01		.07		
45	43	2220	.01	.019	.05	.107	.00	.019	.07	.107	.64
	39	7660	.02		.11		.02		.11		
46	43	2220	.01	.010	.05	.093	.00	.018	.07	.087	.66
	39	4570	.01		.10		.02		.09		

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No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T-75}{\Delta T}$	$\left(\frac{T-75}{\Delta T}\right)_{MOD}$	$\frac{T-50}{\Delta T}$	$\left(\frac{T-50}{\Delta T}\right)_{MOD}$	NEP OF SRSS
47	64	28600	.00	.018	.07	.062	.01	.005	.05	.042	.71
	47	53800	.02		.06		.00		.04		
48	64	28600	.00	.000	.07	.047	.01	.018	.05	.050	.65
	48	57500	.00		.04		.02		.05		
49	67	126000	.02	.020	.15	.146	.02	.019	.14	.138	.86
	53	39500	.02		.10		.01		.11		
50	67	126000	.02	.017	.15	.137	.02	.034	.14	.144	.82
	54	94000	.01		.11		.05		.15		
51	70	22700	.01	.076	.06	.163	.01	.067	.06	.201	.40
	53	71100	.08		.17		.07		.21		
52	70	22700	.01	.079	.06	.218	.01	.050	.06	.109	.64
	60	165000	.08		.22		.05		.11		
53	82	222000	.00	.057	.07	.162	.01	.047	.05	.152	.50
	76	639000	.06		.17		.05		.16		
54	79	29900	.00	.018	.06	.085	.01	.019	.04	.110	.71
	73	64300	.02		.09		.02		.12		
55	44	134	.02	.030	.08	.090	.01	.020	.08	.090	.35
	40	2080	.03		.09		.02		.09		
56	44	134	.02	.020	.08	.050	.01	.000	.08	.010	.60
	41	7670	.02		.05		.00		.01		
57	65	16800	.02	.011	.08	.061	.02	.011	.07	.061	.44
	49	72500	.01		.06		.01		.06		
58	65	16800	.02	.020	.08	.099	.02	.049	.07	.060	.59
	50	96000	.02		.10		.05		.06		

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Table 12 (Cont'd) Combination of Moment A, B, C

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T-75}{\Delta T}$	$\left(\frac{T-75}{\Delta T}\right)_{MOD}$	$\frac{T-50}{\Delta T}$	$\left(\frac{T-50}{\Delta T}\right)_{MOD}$	NEP OF SRSS
59	68	88200	.02	.021	.15	.145	.02	.021	.14	.175	.86
	55	70400	.03		.09		.03		.08		
60	68	88200	.02	.024	.15	.141	.02	.075	.14	.166	.79
	56	60600	.03		.12		.13		.21		
61	71	24800	.01	.076	.05	.181	.01	.067	.06	.210	.54
	61	76600	.08		.19		.07		.22		
62	71	24800	.01	.050	.05	.189	.01	.050	.06	.100	.64
	62	201000	.05		.19		.05		.10		
63	83	17600	.01	.010	.05	.100	.01	.010	.05	.100	.50
	77	391000	.01		.10		.01		.10		
64	80	6770	.00	.029	.06	.117	.01	.029	.05	.126	.60
	74	25000	.03		.12		.03		.13		

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Table 13 Earthquake Combination (5 Hz) 1 of 4

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
1	1	.878	.012	.011	.039	.047	.011	.017	.044	.045	.79
	2	.566	.008		.013		.016		.048		
2	3	.339	.005	.006	.012	.014	.000	.006	.012	.015	.96
	4	.415	.007		.016		.008		.017		
3	5	.285	.017	.017	.032	.036	.009	.009	.040	.044	.75
	6	.055	.021		.067		.011		.073		
4	7	.075	.007	.010	.044	.058	.007	.011	.037	.044	.85
	8	.101	.011		.065		.013		.048		
5	9	.083	.007	.025	.045	.130	.008	.027	.045	.122	.60
	10	.452	.025		.132		.027		.124		
6	11	.533	.016	.015	.051	.056	.011	.012	.056	.055	.77
	12	.325	.013		.056		.015		.052		
7	13	.182	.005	.006	.049	.059	.011	.008	.035	.027	.82
	14	.166	.007		.023		.000		.013		
8	15	.164	.005	.010	.045	.052	.005	.007	.035	.042	.84
	16	.122	.016		.063		.009		.052		
9	17	.096	.007	.006	.040	.040	.003	.003	.029	.028	.89
	18	.062	.004		.039		.003		.027		
10	19	.154	.012	.010	.053	.042	.007	.006	.035	.028	.91
	20	.124	.004		.015		.003		.013		
11	21	.081	.003	.005	.003	.024	.008	.004	.028	.023	.86
	22	.452	.005		.024		.004		.023		
12	23	.455	.007	.007	.035	.036	.003	.005	.039	.040	.84
	24	.228	.007		.049		.015		.055		

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Table 13 (Cont'd) Earthquake Combination (5 Hz)

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
13	25	.297	.006	.008	.020	.019	.007	.004	.024	.022	.91
	26	.208	.005		.019		.001		.021		
14	27	.265	.013	.007	.079	.021	.011	.007	.073	.023	.57
	28	.273	.005		.012		.007		.016		
15	29	.250	.009	.008	.025	.025	.007	.007	.025	.025	.96
	30	.150	.004		.019		.005		.019		
16	31	.109	.005	.007	.055	.054	.009	.012	.048	.045	.76
	32	.167	.008		.053		.013		.044		
17	33	.041	.023	.022	.115	.147	.029	.027	.115	.147	.59
	34	.020	.013		.084		.013		.064		
18	35	.035	.011	.012	.036	.041	.003	.007	.045	.038	.69
	36	.015	.017		.061		.017		.044		
19	37	.207	.005	.009	.023	.028	.007	.010	.027	.028	.96
	38	.205	.012		.033		.012		.029		
20	39	.078	.004	.004	.024	.013	.005	.003	.031	.016	.89
	40	.155	.004		.009		.003		.009		
21	41	.144	.009	.010	.049	.036	.011	.011	.048	.035	.84
	42	.167	.011		.023		.011		.020		
22	43	.124	.003	.005	.011	.021	.003	.007	.011	.021	.96
	44	.338	.005		.023		.008		.023		
23	45	.057	.008	.009	.020	.024	.005	.007	.020	.024	.95
	46	.252	.009		.024		.007		.024		
24	47	.206	.005	.006	.013	.017	.005	.005	.015	.020	.98
	48	.129	.008		.025		.005		.029		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
25	47	.144	.004	.004	.012	.018	.005	.006	.011	.018	.83
	48	.070	.005		.032		.009		.035		
26	51	.096	.006	.007	.020	.032	.004	.007	.019	.023	.91
	52	.199	.007		.033		.007		.023		
27	53	.324	.000	.001	.015	.015	.004	.004	.012	.012	.89
	54	.121	.004		.015		.001		.012		
28	55	.247	.009	.016	.025	.057	.004	.013	.026	.059	.79
	56	.154	.024		.089		.021		.091		
29	57	.131	.017	.014	.089	.074	.011	.010	.076	.066	.87
	58	.087	.004		.036		.007		.033		
30	59	.054	.007	.010	.032	.039	.005	.010	.033	.042	.87
	60	.045	.017		.056		.019		.063		
31	61	.372	.005	.004	.024	.022	.008	.007	.024	.020	.97
	62	.327	.003		.019		.005		.012		
32	63	.381	.005	.005	.039	.041	.009	.009	.033	.035	.71
	64	.090	.005		.068		.013		.059		
33	65	.169	.009	.010	.049	.050	.016	.015	.053	.055	.98
	66	.057	.016		.060		.007		.068		
34	67	.072	.008	.008	.047	.042	.007	.007	.041	.035	.91
	68	.033	.009		.035		.008		.027		
35	69	.227	.008	.011	.045	.061	.005	.007	.033	.052	.87
	70	.618	.011		.061		.009		.052		
36	71	.555	.004	.005	.037	.035	.004	.004	.035	.037	.72
	72	.214	.008		.047		.004		.049		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
37	73	.016	.001	.004	.015	.012	.005	.004	.013	.011	.97
	74	.0271	.005		.011		.004		.011		
38	75	.173	.004	.005	.011	.015	.007	.005	.013	.012	.97
	76	.0[illegible]1	.00[illegible]		.013		.004		.012		

BEST DOCUMENT AVAILABLE

Table 14 Earthquake Combination (10 Hz) 1 of 4

No.	SET No.	PEAK VALUE	$T_{75}/\Delta T$	$(T_{75}/\Delta T)_{MOD}$	$T_{50}/\Delta T$	$(T_{50}/\Delta T)_{MOD}$	$T_{-75}/\Delta T$	$(T_{-75}/\Delta T)_{MOD}$	$T_{-50}/\Delta T$	$(T_{-50}/\Delta T)_{MOD}$	NEP OF SRSS
1	1	.174	.026	.002	.016	.021	.005	.005	.015	.015	.91
	2	.073	.005		.037		.006		.023		
2	3	.290	.033	.008	.016	.016	.017	.007	.012	.012	.78
	4	.089	.033		.033		.014		.015		
3	5	.044	.005	.005	.032	.031	.000	.001	.033	.032	.89
	6	.012	.001		.019		.005		.021		
4	7	.013	.001	.011	.020	.047	.007	.009	.035	.052	.91
	8	.013	.015		.063		.011		.064		
5	9	.010	.004	.008	.044	.037	.003	.007	.053	.036	.76
	10	.055	.008		.037		.007		.035		
6	11	.043	.011	.007	.059	.047	.011	.008	.045	.041	.70
	12	.057	.001		.035		.005		.037		
7	13	.021	.005	.008	.045	.035	.023	.013	.072	.043	.92
	14	.029	.009		.028		.000		.007		
8	15	.014	.012	.009	.059	.057	.004	.007	.044	.049	.81
	16	.013	.004		.055		.009		.055		
9	17	.012	.007	.009	.053	.053	.000	.001	.047	.045	.77
	18	.005	.017		.052		.003		.035		
10	19	.016	.005	.009	.040	.049	.005	.011	.039	.046	.71
	20	.013	.013		.061		.016		.055		
11	21	.005	.001	.005	.037	.027	.009	.003	.044	.025	.79
	22	.016	.005		.027		.003		.024		
12	23	.053	.007	.007	.023	.023	.004	.004	.016	.018	.84
	24	.055	.007		.023		.005		.023		

BEST DOCUMENT AVAILABLE

Table 14 (Cont'd) Earthquake Combination (10 Hz) 2 of 4

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
13	25	.050	.011	.010	.025	.021	.004	.003	.021	.018	.95
	26	.049	.008		.016		.000		.015		
14	27	.013	.007	.004	.032	.024	.008	.005	.035	.021	.73
	28	.025	.003		.011		.004		.017		
15	29	.050	.001	.004	.008	.013	.000	.001	.001	.014	.97
	30	.026	.007		.020		.001		.025		
16	31	.012	.011	.012	.051	.055	.008	.007	.048	.053	.77
	32	.013	.012		.059		.007		.057		
17	33	.009	.008	.008	.053	.052	.013	.013	.040	.040	.69
	34	.0028	.008		.045		.013		.035		
18	35	.0057	.025	.006	.055	.053	.011	.011	.033	.037	.95
	36	.0014	.011		.041		.009		.059		
19	37	.015	.001	.003	.013	.020	.003	.004	.005	.019	.94
	38	.014	.004		.025		.005		.027		
20	39	.019	.005	.004	.012	.009	.005	.004	.023	.015	.95
	40	.028	.004		.008		.003		.008		
21	41	.014	.005	.008	.017	.028	.004	.009	.027	.037	.89
	42	.012	.011		.039		.013		.048		
22	43	.037	.004	.007	.016	.018	.004	.009	.016	.020	.94
	44	.056	.008		.019		.011		.021		
23	45	.017	.008	.004	.029	.020	.009	.004	.027	.015	.92
	46	.046	.003		.019		.003		.013		
24	47	.030	.001	.004	.011	.013	.001	.002	.013	.016	.94
	48	.017	.007		.019		.004		.023		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP. OF SRSS
25	49	.015	.001	.001	.011	.009	.003	.002	.011	.009	.96
	50	.013	.001		.007		.000		.007		
26	51	.011	.000	.004	.019	.040	.001	.010	.012	.045	.90
	52	.019	.005		.045		.012		.051		
27	53	.049	.000	.001	.005	.011	.004	.004	.009	.011	.72
	54	.012	.005		.031		.004		.028		
28	55	.035	.000	.004	.011	.023	.003	.003	.009	.017	.88
	56	.019	.008		.043		.001		.032		
29	57	.026	.001	.002	.024	.024	.001	.001	.023	.022	.92
	58	.010	.004		.024		.000		.013		
30	59	.0097	.005	.006	.033	.044	.005	.005	.023	.032	.75
	60	.0043	.008		.053		.007		.059		
31	61	.068	.004	.004	.019	.017	.007	.006	.019	.016	.97
	62	.048	.005		.013		.003		.009		
32	63	.046	.005	.005	.025	.024	.005	.005	.025	.024	.95
	64	.013	.003		.012		.001		.011		
33	65	.027	.005	.005	.017	.017	.007	.006	.028	.026	.97
	66	.013	.003		.017		.003		.017		
34	67	.0098	.001	.002	.009	.012	.001	.002	.008	.011	.98
	68	.0089	.003		.015		.003		.013		
35	69	.0042	.003	.003	.035	.044	.004	.015	.023	.047	.84
	70	.063	.003		.044		.015		.047		
36	71	.097	.001	.004	.012	.022	.001	.004	.013	.025	.95
	72	.060	.007		.036		.007		.043		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
57	73	.067	.004	.003	.024	.020	.005	.004	.021	.017	.95
	74	.054	.001		.009		.001		.009		
58	75	.097	.004	.003	.013	.014	.004	.004	.015	.016	.96
	76	.089	.001		.017		.004		.019		

BEST DOCUMENT AVAILABLE

Table 15 Earthquake Combination (15 Hz)

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
1	1	.0476	.000	.002	.013	.017	.004	.004	.015	.018	.93
	2	.0202	.004		.032		.004		.031		
2	3	.0457	.003	.003	.017	.017	.001	.002	.023	.023	.65
	4	.0062	.003		.005		.008		.016		
3	5	.0056	.007	.006	.020	.019	.000	.002	.013	.013	.88
	6	.0036	.001		.009		.004		.012		
4	7	.0037	.005	.016	.039	.057	.011	.019	.039	.058	.77
	8	.0042	.021		.068		.023		.069		
5	9	.0024	.004	.005	.056	.033	.005	.005	.065	.042	.76
	10	.0129	.005		.032		.005		.041		
6	11	.0154	.003	.004	.027	.027	.004	.003	.024	.025	.90
	12	.0099	.005		.028		.000		.027		
7	13	.0069	.007	.008	.055	.039	.029	.016	.075	.042	.93
	14	.0102	.009		.029		.000		.004		
8	15	.0037	.011	.007	.053	.043	.005	.004	.031	.027	.87
	16	.0050	.001		.036		.003		.025		
9	17	.0039	.007	.010	.061	.059	.001	.001	.052	.048	.83
	18	.0018	.017		.045		.000		.025		
10	19	.0047	.009	.005	.040	.044	.004	.004	.049	.045	.89
	20	.0041	.005		.049		.004		.039		
11	21	.0024	.009	.015	.039	.040	.003	.005	.045	.032	.67
	22	.0129	.015		.040		.005		.031		
12	23	.0199	.011	.010	.033	.029	.011	.010	.028	.025	.84
	24	.0105	.001		.005		.004		.009		

BEST DOCUMENT AVAILABLE

Table 15 (Cont'd) Earthquake Combination (15 Hz)

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
13	25	.0125	.025	.016	.041	.026	.009	.005	.040	.024	.97
	26	.0175	.007		.013		.000		.009		
14	27	.0035	.015	.006	.047	.018	.009	.003	.053	.020	.72
	28	.0097	.003		.009		.001		.009		
15	29	.0111	.003	.003	.007	.008	.003	.003	.007	.008	.96
	30	.0047	.003		.013		.003		.012		
16	31	.0028	.012	.007	.068	.055	.015	.011	.065	.060	.74
	32	.0043	.004		.048		.008		.045		
17	33	.0017	.001	.002	.024	.023	.000	.002	.017	.016	.91
	34	.0011	.003		.019		.003		.013		
18	35	.0013	.003	.003	.037	.036	.009	.009	.025	.026	.97
	36	.0004	.001		.027		.001		.033		
19	37	.0035	.003	.006	.016	.025	.005	.007	.013	.029	.88
	38	.0038	.007		.031		.008		.037		
20	39	.0039	.001	.001	.031	.021	.011	.007	.024	.016	.94
	40	.0051	.001		.013		.000		.007		
21	41	.0044	.000	.003	.011	.012	.003	.006	.005	.013	.96
	42	.0035	.005		.013		.008		.020		
22	43	.0086	.004	.003	.009	.010	.003	.002	.015	.012	.97
	44	.0110	.001		.011		.001		.009		
23	45	.0052	.000	.003	.016	.011	.003	.004	.013	.012	.97
	46	.0079	.003		.008		.004		.012		
24	47	.0053	.007	.006	.017	.018	.009	.008	.024	.022	.92
	48	.0046	.004		.020		.005		.019		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
25	49	.0037	.004	.004	.013	.016	.001	.002	.005	.013	.91
	50	.0023	.005		.021		.004		.024		
26	51	.0036	.005	.004	.027	.047	.008	.005	.024	.054	.61
	52	.0059	.003		.053		.004		.061		
27	53	.0140	.000	.001	.012	.013	.005	.005	.012	.013	.74
	54	.0038	.004		.023		.001		.020		
28	55	.0118	.000	.003	.015	.029	.003	.004	.009	.020	.87
	56	.0047	.008		.069		.008		.049		
29	57	.0037	.013	.012	.044	.039	.013	.011	.051	.042	.72
	58	.0026	.011		.027		.001		.013		
30	59	.0024	.011	.010	.043	.042	.003	.003	.024	.023	.84
	60	.0014	.001		.037		.004		.019		
31	61	.0164	.003	.004	.025	.021	.004	.004	.036	.030	.91
	62	.0127	.005		.013		.003		.017		
32	63	.0151	.008	.008	.019	.018	.008	.008	.025	.024	.93
	64	.0049	.001		.007		.001		.007		
33	65	.0076	.004	.004	.044	.040	.008	.008	.056	.051	.92
	66	.0038	.001		.013		.007		.016		
34	67	.0036	.003	.002	.007	.006	.001	.001	.005	.006	.99
	68	.0032	.001		.005		.001		.007		
35	69	.0012	.005	.000	.044	.013	.007	.004	.029	.023	.65
	70	.0240	.000		.013		.004		.023		
36	71	.0219	.001	.002	.007	.016	.001	.004	.011	.022	.88
	72	.0112	.005		.033		.009		.043		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
37	73	.250	.000	.000	.005	.005	.003	.003	.008	.008	.98
	74	.020	.001		.008		.003		.007		
38	75	.0132	.004	.003	.020	.016	.008	.006	.019	.015	.99
	76	.0116	.000		.009		.003		.007		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
1	1	5.03	.016	.014	.044	.050	.013	.012	.040	.048	.81
	2	3.72	.009		.063		.011		.064		
2	3	3.73	.016	.014	.051	.044	.015	.013	.051	.045	.89
	4	2.54	.009		.021		.008		.028		
3	5	2.31	.011	.011	.045	.043	.007	.007	.043	.043	.87
	6	0.37	.009		.056		.011		.059		
4	7	0.30	.004	.006	.067	.069	.004	.011	.061	.063	.74
	8	0.23	.009		.073		.017		.067		
5	9	0.39	.019	.020	.081	.060	.023	.017	.081	.053	.65
	10	3.56	.020		.060		.017		.053		
6	11	3.56	.015	.016	.053	.063	.016	.017	.053	.062	.81
	12	2.42	.017		.080		.019		.079		
7	13	0.45	.005	.007	.045	.049	.013	.009	.063	.048	.88
	14	0.50	.009		.031		.004		.032		
8	15	2.12	.016	.016	.036	.036	.019	.018	.036	.037	.85
	16	0.79	.013		.035		.012		.040		
9	17	0.36	.005	.008	.051	.055	.009	.014	.043	.052	.79
	18	0.31	.011		.059		.019		.063		
10	19	1.12	.015	.015	.051	.054	.012	.014	.049	.050	.83
	20	0.53	.016		.065		.021		.053		
11	21	0.54	.024	.013	.067	.031	.023	.009	.076	.029	.79
	22	2.62	.012		.028		.008		.025		
12	23	3.35	.011	.015	.041	.057	.016	.018	.037	.054	.79
	24	1.30	.031		.117		.028		.116		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
13	25	1.61	.001	.006	.021	.024	.003	.009	.023	.022	.95
	26	2.09	.008		.025		.009		.021		
14	27	0.34	.016	.016	.075	.044	.013	.013	.053	.047	.54
	28	0.78	.016		.033		.013		.036		
15	29	1.03	.032	.025	.079	.069	.029	.025	.081	.072	.85
	30	0.63	.011		.032		.011		.036		
16	31	0.66	.025	.020	.088	.079	.024	.020	.084	.089	.60
	32	0.53	.009		.063		.009		.057		
17	33	0.44	.013	.019	.077	.088	.013	.018	.077	.089	.63
	34	0.13	.051		.172		.048		.177		
18	35	0.12	.019	.018	.054	.070	.015	.014	.099	.082	.72
	36	0.10	.016		.044		.013		.047		
19	37	0.87	.005	.014	.037	.040	.008	.014	.037	.042	.91
	38	0.81	.019		.044		.019		.047		
20	39	0.62	.019	.019	.048	.059	.017	.015	.045	.058	.64
	40	0.34	.021		.087		.020		.088		
21	41	0.53	.009	.008	.039	.035	.012	.009	.044	.038	.89
	42	0.67	.008		.032		.007		.033		
22	43	2.20	.019	.015	.040	.035	.021	.017	.041	.036	.94
	44	1.66	.005		.023		.003		.023		
23	45	1.00	.011	.010	.024	.028	.008	.009	.023	.028	.95
	46	1.21	.009		.031		.009		.031		
24	47	0.84	.011	.013	.036	.047	.011	.016	.031	.041	.87
	48	0.67	.016		.060		.021		.053		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
25	49	.80	.012	.014	.031	.036	.013	.015	.032	.038	.93
	50	.98	.015		.039		.016		.041		
26	51	.45	.011	.015	.036	.030	.011	.012	.032	.032	.88
	52	1.47	.015		.029		.012		.032		
27	53	1.90	.011	.013	.035	.040	.011	.013	.035	.039	.93
	54	.49	.027		.085		.027		.060		
28	55	1.75	.019	.019	.067	.070	.016	.017	.071	.074	.68
	56	.79	.021		.084		.020		.089		
29	57	.60	.016	.016	.055	.085	.021	.021	.089	.089	.71
	58	.28	.016		.087		.019		.087		
30	59	.28	.020	.019	.079	.054	.016	.018	.076	.082	.72
	60	.19	.015		.093		.023		.093		
31	61	2.01	.011	.009	.053	.052	.009	.008	.053	.051	.82
	62	1.27	.003		.051		.004		.047		
32	63	2.31	.015	.015	.033	.034	.016	.016	.039	.040	.66
	64	.30	.017		.061		.013		.071		
33	65	.49	.009	.018	.072	.080	.011	.019	.068	.076	.76
	66	.49	.024		.087		.024		.083		
34	67	.30	.011	.010	.041	.032	.011	.010	.041	.033	.90
	68	.31	.009		.021		.009		.023		
35	69	.19	.009	.041	.035	.148	.008	.039	.029	.152	.73
	70	2.93	.041		.148		.039		.152		
36	71	3.03	.009	.009	.024	.032	.008	.009	.024	.034	.74
	72	1.58	.011		.053		.012		.057		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
37	73	3.43	.012	.011	.040	.038	.012	.011	.039	.033	.92
	74	2.02	.008		.031		.009		.028		
38	75	1.55	.017	.017	.057	.054	.020	.022	.053	.052	.89
	76	2.47	.017		.053		.023		.052		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
1	1	28.33	.017	.015	.047	.050	.021	.019	.053	.052	.67
	2	19.74	.008		.056		.016		.051		
2	3	20.27	.005	.005	.027	.026	.007	.007	.028	.027	.89
	4	12.09	.004		.024		.005		.024		
3	5	12.59	.007	.007	.027	.028	.007	.007	.024	.025	.70
	6	2.30	.008		.043		.005		.037		
4	7	2.68	.001	.004	.032	.041	.004	.004	.028	.040	.90
	8	2.99	.005		.047		.004		.047		
5	9	2.53	.003	.017	.051	.075	.005	.019	.051	.065	.67
	10	16.07	.017		.075		.019		.065		
6	11	18.35	.013	.014	.037	.049	.013	.012	.049	.056	.69
	12	11.24	.016		.072		.011		.072		
7	13	4.48	.008	.013	.059	.047	.020	.013	.069	.048	.78
	14	5.27	.015		.036		.003		.023		
8	15	9.99	.007	.007	.025	.028	.007	.007	.028	.029	.87
	16	4.34	.007		.041		.007		.036		
9	17	2.55	.009	.008	.068	.063	.007	.007	.059	.057	.65
	18	1.69	.005		.048		.007		.053		
10	19	6.50	.004	.003	.031	.030	.003	.003	.024	.024	.89
	20	4.08	.000		.029		.003		.025		
11	21	2.92	.005	.008	.033	.027	.003	.004	.037	.025	.74
	22	14.88	.008		.027		.004		.024		
12	23	24.96	.005	.005	.021	.021	.003	.003	.016	.018	.90
	24	9.01	.000		.021		.005		.029		

BEST DOCUMENT AVAILABLE

Table 17 (Cont'd) 7 Degrees of Freedom (Z)

No.	SET No.	PEAK VALUE	$T_{75}/\Delta T$	$(T_{75}/\Delta T)_{MOD}$	$T_{50}/\Delta T$	$(T_{50}/\Delta T)_{MOD}$	$T_{-75}/\Delta T$	$(T_{-75}/\Delta T)_{MOD}$	$T_{-50}/\Delta T$	$(T_{-50}/\Delta T)_{MOD}$	NEP OF SRSS
13	25	11.20	.005	.004	.021	.013	.007	.004	.019	.011	.96
	26	17.78	.004		.007		.000		.004		
14	27	2.65	.003	.008	.030	.029	.024	.007	.031	.022	.56
	28	7.65	.008		.027		.007		.021		
15	29	10.46	.004	.004	.015	.017	.003	.003	.016	.018	.91
	30	4.62	.004		.023		.023		.025		
16	31	3.58	.008	.007	.067	.055	.024	.003	.060	.048	.76
	32	3.82	.005		.041		.001		.033		
17	33	1.91	.023	.021	.083	.081	.021	.019	.079	.076	.43
	34	0.85	.008		.073		.008		.051		
18	35	1.12	.004	.005	.021	.023	.004	.005	.020	.026	.76
	36	0.46	.008		.032		.008		.045		
19	37	4.86	.006	.004	.023	.023	.005	.003	.023	.021	.93
	38	5.35	.004		.023		.001		.020		
20	39	2.98	.013	.009	.051	.041	.009	.006	.043	.039	.83
	40	3.10	.003		.029		.008		.035		
21	41	2.71	.009	.010	.037	.027	.011	.009	.040	.031	.78
	42	3.76	.011		.019		.008		.025		
22	43	11.97	.005	.005	.017	.013	.007	.005	.017	.013	.96
	44	14.01	.005		.008		.003		.009		
23	45	4.79	.008	.003	.016	.009	.007	.004	.015	.008	.97
	46	10.97	.000		.007		.003		.005		
24	47	7.50	.003	.004	.008	.016	.003	.004	.008	.016	.93
	48	4.63	.005		.028		.005		.028		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
25	49	4.87	.004	.006	.020	.026	.004	.006	.019	.027	.91
	50	4.59	.008		.031		.007		.033		
26	51	1.92	.009	.005	.029	.020	.006	.004	.032	.021	.84
	52	7.61	.005		.019		.004		.020		
27	53	15.66	.010	.001	.006	.010	.007	.007	.013	.014	.78
	54	5.64	.005		.027		.004		.023		
28	55	10.27	.000	.003	.017	.027	.003	.005	.028	.036	.83
	56	4.59	.008		.053		.011		.063		
29	57	3.86	.005	.004	.045	.042	.004	.004	.039	.036	.89
	58	2.20	.001		.032		.005		.027		
30	59	1.74	.017	.015	.075	.068	.021	.018	.075	.070	.69
	60	1.08	.008		.044		.009		.053		
31	61	11.65	.003	.005	.031	.026	.012	.009	.043	.035	.93
	62	9.55	.007		.016		.001		.015		
32	63	11.36	.009	.009	.023	.023	.007	.007	.021	.021	.94
	64	2.89	.006		.023		.003		.016		
33	65	5.03	.007	.007	.039	.042	.005	.005	.055	.054	.71
	66	1.64	.008		.053		.005		.049		
34	67	2.55	.004	.003	.009	.008	.000	.002	.005	.007	.99
	68	2.87	.001		.007		.003		.008		
35	69	1.42	.001	.007	.011	.065	.005	.007	.011	.065	.80
	70	15.53	.007		.065		.007		.065		
36	71	16.65	.004	.005	.028	.028	.004	.005	.028	.028	.83
	72	5.74	.007		.027		.007		.029		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
37	73	19.397	.005	.004	.017	.018	.004	.005	.019	.018	.95
	74	12.97	.003		.019		.007		.017		
38	71	8.84	.009	.008	.021	.024	.009	.008	.021	.025	.95
	72	13.23	.007		.025		.008		.027		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
1	1	34.96	.011	.010	.043	.046	.009	.010	.048	.049	.69
	2	22.52	.007		.052		.011		.052		
2	3	34.77	.005	.005	.016	.016	.005	.005	.017	.017	.69
	4	14.82	.001		.015		.003		.017		
3	5	13.40	.008	.008	.028	.029	.008	.008	.027	.028	.69
	6	2.69	.008		.047		.007		.047		
4	7	3.29	.003	.009	.044	.050	.007	.008	.037	.052	.94
	8	3.95	.011		.053		.008		.060		
5	9	2.92	.008	.013	.068	.071	.008	.012	.055	.057	.78
	10	18.26	.013		.071		.012		.057		
6	11	21.78	.005	.008	.039	.041	.008	.007	.036	.037	.79
	12	14.45	.012		.045		.004		.039		
7	13	5.33	.024	.017	.072	.047	.044	.025	.095	.055	.76
	14	7.69	.012		.031		.000		.019		
8	15	10.39	.007	.007	.031	.036	.007	.007	.027	.032	.85
	16	4.95	.008		.051		.009		.048		
9	17	3.18	.016	.014	.085	.076	.012	.010	.064	.060	.96
	18	2.01	.007		.048		.004		.048		
10	19	7.15	.007	.006	.033	.035	.003	.003	.032	.033	.85
	20	4.60	.003		.039		.004		.036		
11	21	3.21	.003	.008	.028	.031	.004	.003	.036	.021	.74
	22	17.75	.008		.031		.003		.020		
12	23	29.44	.007	.007	.023	.025	.004	.005	.012	.017	.86
	24	9.36	.003		.041		.011		.040		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
13	25	15.49	.004	.004	.020	.014	.005	.003	.017	.011	.97
	26	21.09	.004		.009		.000		.004		
14	27	3.03	.013	.008	.047	.026	.012	.006	.049	.023	.46
	28	9.80	.007		.023		.005		.019		
15	29	13.08	.004	.004	.011	.011	.003	.003	.012	.011	.95
	30	7.02	.005		.011		.000		.009		
16	31	4.17	.007	.007	.061	.096	.007	.006	.053	.050	.72
	32	4.52	.007		.052		.005		.047		
17	33	2.10	.015	.014	.081	.078	.017	.016	.068	.065	.69
	34	1.02	.007		.064		.007		.053		
18	35	1.41	.005	.006	.021	.022	.007	.007	.023	.026	.69
	36	0.53	.012		.031		.004		.039		
19	37	6.00	.001	.002	.020	.022	.004	.003	.015	.020	.94
	38	6.19	.003		.023		.001		.023		
20	39	4.36	.001	.005	.024	.021	.001	.001	.029	.025	.93
	40	4.45	.007		.017		.001		.020		
21	41	3.48	.004	.007	.033	.025	.005	.006	.029	.026	.85
	42	4.62	.008		.020		.007		.024		
22	43	13.68	.003	.003	.015	.011	.001	.001	.015	.011	.97
	44	16.12	.003		.008		.001		.008		
23	45	5.89	.004	.002	.015	.007	.003	.003	.015	.009	.96
	46	13.00	.000		.004		.003		.007		
24	47	8.96	.003	.004	.008	.012	.000	.003	.011	.014	.93
	48	5.44	.007		.020		.005		.021		

BEST DOCUMENT AVAILABLE

Table 18 (Cont'd) 30 Degrees of Freedom (X)

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
25	49	5.76	.005	.006	.017	.025	.004	.004	.019	.028	.90
	50	4.76	.008		.033		.004		.037		
26	51	2.31	.007	.003	.023	.017	.005	.005	.028	.021	.87
	52	5.18	.003		.017		.005		.020		
27	53	15.73	.001	.002	.007	.009	.008	.008	.017	.018	.65
	54	4.13	.008		.021		.003		.027		
28	55	13.46	.000	.003	.005	.022	.003	.006	.013	.027	.84
	56	5.31	.007		.059		.013		.065		
29	57	3.99	.015	.015	.059	.055	.005	.008	.069	.062	.72
	58	2.37	.015		.044		.007		.035		
30	59	2.33	.009	.009	.056	.056	.007	.008	.055	.059	.74
	60	1.15	.009		.064		.012		.072		
31	61	14.46	.003	.004	.027	.021	.009	.007	.032	.024	.96
	62	13.50	.004		.011		.000		.007		
32	63	12.64	.008	.008	.023	.023	.007	.007	.020	.020	.92
	64	4.63	.008		.028		.004		.017		
33	65	6.26	.011	.010	.065	.061	.012	.011	.075	.071	.90
	66	3.04	.008		.040		.004		.048		
34	67	2.93	.004	.003	.011	.008	.000	.002	.005	.005	.99
	68	3.55	.000		.005		.003		.005		
35	69	1.60	.001	.001	.013	.039	.005	.007	.015	.053	.77
	70	20.60	.001		.039		.007		.053		
36	71	20.42	.000	.002	.017	.024	.007	.007	.027	.031	.79
	72	10.49	.005		.041		.007		.043		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T-75}{\Delta T}$	$\left(\frac{T-75}{\Delta T}\right)_{MOD}$	$\frac{T-50}{\Delta T}$	$\left(\frac{T-50}{\Delta T}\right)_{MOD}$	NEP OF SRSS
37	73	17.93	.009	.008	.023	.022	.028	.024	.020	.022	.91
	74	12.94	.007		.020		.011		.025		
38	75	12.66	.003	.002	.012	.015	.001	.006	.017	.016	.97
	76	17.53	.001		.017		.007		.016		

BEST DOCUMENT AVAILABLE

No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T-75}{\Delta T}$	$\left(\frac{T-75}{\Delta T}\right)_{MOD}$	$\frac{T-50}{\Delta T}$	$\left(\frac{T-50}{\Delta T}\right)_{MOD}$	NEP OF SRSS
1	1	16.33	.005	.005	.025	.029	.007	.007	.028	.032	.96
	2	7.49	.004		.045		.005		.047		
2	3	10.65	.004	.004	.015	.015	.005	.005	.011	.011	.72
	4	4.36	.005		.023		.008		.023		
3	5	4.42	.005	.005	.027	.026	.001	.001	.017	.017	.89
	6	1.25	.003		.017		.003		.020		
4	7	1.24	.001	.010	.017	.048	.005	.008	.027	.047	.92
	8	1.19	.015		.067		.011		.061		
5	9	0.99	.017	.005	.063	.030	.013	.003	.068	.029	.76
	10	7.03	.004		.029		.003		.028		
6	11	7.65	.000	.005	.021	.032	.003	.006	.019	.027	.89
	12	6.16	.008		.044		.009		.036		
7	13	1.92	.008	.010	.060	.040	.027	.016	.073	.044	.88
	14	2.63	.011		.023		.000		.012		
8	15	2.87	.007	.007	.024	.027	.007	.006	.023	.028	.85
	16	1.50	.005		.035		.003		.041		
9	17	1.05	.012	.012	.068	.066	.008	.007	.055	.055	.94
	18	0.96	.012		.060		.003		.053		
10	19	1.82	.008	.007	.041	.042	.011	.009	.040	.041	.74
	20	1.43	.004		.044		.005		.043		
11	21	0.99	.012	.012	.039	.037	.009	.008	.035	.025	.75
	22	5.27	.012		.037		.008		.025		
12	23	7.72	.005	.005	.027	.027	.009	.009	.028	.028	.80
	24	5.58	.005		.028		.008		.027		

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No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T_{-75}}{\Delta T}$	$\left(\frac{T_{-75}}{\Delta T}\right)_{MOD}$	$\frac{T_{-50}}{\Delta T}$	$\left(\frac{T_{-50}}{\Delta T}\right)_{MOD}$	NEP OF SRSS
13	25	5.14	.007	.009	.021	.022	.004	.004	.013	.021	.94
	26	4.32	.011		.024		.005		.028		
14	27	1.21	.012	.005	.005	.025	.012	.006	.047	.019	.70
	28	3.04	.003		.009		.004		.009		
15	29	4.12	.003	.003	.011	.012	.000	.000	.005	.011	.97
	30	3.10	.003		.013		.000		.017		
16	31	1.46	.007	.006	.047	.052	.004	.005	.043	.049	.66
	32	1.40	.005		.056		.005		.055		
17	33	0.94	.008	.008	.069	.067	.013	.013	.049	.048	.74
	34	0.31	.003		.043		.007		.037		
18	35	0.41	.005	.006	.032	.031	.007	.007	.021	.023	.71
	36	0.18	.009		.028		.007		.033		
19	37	1.96	.009	.009	.016	.024	.004	.008	.019	.028	.92
	38	1.49	.008		.031		.011		.036		
20	39	2.22	.004	.004	.016	.013	.005	.004	.016	.012	.95
	40	2.74	.004		.011		.003		.009		
21	41	1.42	.007	.008	.028	.028	.005	.004	.025	.032	.90
	42	1.57	.008		.028		.003		.037		
22	43	4.59	.003	.004	.016	.015	.001	.006	.019	.016	.94
	44	6.40	.005		.015		.007		.015		
23	45	2.82	.004	.004	.019	.015	.004	.004	.019	.020	.94
	46	4.61	.004		.013		.004		.020		
24	47	3.18	.003	.003	.017	.014	.003	.002	.015	.016	.95
	48	2.12	.004		.016		.000		.019		

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No.	SET No.	PEAK VALUE	$\frac{T_{75}}{\Delta T}$	$\left(\frac{T_{75}}{\Delta T}\right)_{MOD}$	$\frac{T_{50}}{\Delta T}$	$\left(\frac{T_{50}}{\Delta T}\right)_{MOD}$	$\frac{T-75}{\Delta T}$	$\left(\frac{T-75}{\Delta T}\right)_{MOD}$	$\frac{T-50}{\Delta T}$	$\left(\frac{T-50}{\Delta T}\right)_{MOD}$	NEP OF SRSS
25	49	1.59	.005	.004	.019	.019	.004	.003	.015	.020	.88
	50	1.46	.003		.020		.001		.024		
26	51	1.18	.003	.006	.016	.029	.003	.014	.024	.030	.90
	52	2.30	.007		.031		.004		.031		
27	53	4.79	.000	.002	.012	.014	.004	.004	.009	.013	.73
	54	1.25	.007		.031		.005		.036		
28	55	4.19	.000	.002	.001	.020	.003	.004	.009	.017	.88
	56	1.98	.005		.047		.007		.035		
29	57	2.28	.007	.007	.040	.037	.007	.006	.048	.044	.86
	58	1.01	.007		.019		.000		.016		
30	59	1.05	.004	.004	.027	.029	.004	.004	.024	.029	.82
	60	0.54	.001		.036		.004		.043		
31	61	6.79	.001	.002	.023	.021	.009	.007	.025	.021	.91
	62	4.97	.003		.016		.001		.009		
32	63	5.67	.003	.003	.019	.019	.003	.003	.020	.020	.94
	64	1.31	.004		.016		.001		.015		
33	65	2.53	.003	.004	.021	.024	.007	.008	.028	.028	.80
	66	1.18	.007		.033		.011		.029		

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5.0 CONCLUSIONS

1) A simplified NEP vs. σ/R_{max} graph can be drawn as shown in Figure 2. For qualifying SRSS as the combination results, σ/R_{max} (or its modified form) must be below 0.29 if the acceptable NEP is 0.84; and σ/R_{max} must be below 0.37 if the acceptable NEP is 0.50.

2) Most real earthquake loads and responses appear to have σ/R_{max} values less than 0.37. This conclusion is based on the study of response for structures with a dominant frequency of 5 Hz or higher, and with a hypothetical reactor system.

3) In order to qualify SRSS as the combination rule, it is necessary to investigate the response characteristic. The characteristic of the input time-history appears to be unreliable for qualifying the SRSS rule.

4) Most earthquake responses appear to have a value σ/R_{max} less than 0.37. When two earthquake responses are combined with randomly distributed time lag for the second responses, the NEP of SRSS value lies above 0.5 most of the time.

5) It may be stated that earthquake type responses can be combined with the SRSS rule provided that the loads were determined probabilistically at an NEP level of 0.84 or above.

6) Dynamic loads other than earthquakes must be analyzed using a time-history analysis. The load definition must be specified probabilistically at an NEP level of 0.84 or higher. If this is done, then the SRSS combination rule can be used for the case in which the σ/R_{max} value of the response history $\leq$ 0.37.

7) If the criterion stated in 6 is not satisfied, then one of the following more elaborate methods must be used.

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A) Obtain the response time-history of all dynamic loads. The time-history can then be combined with the time lag, so that a CDF function can be plotted as was discussed in Sec. 1.1. If SRSS is located at an NEP of 0.5 or greater and 1.2* SRSS is located at an NEP of 0.85 or greater then it can be used as a combined response.

B) The absolute sum of the peak responses can be used as a combined response.

C) The threshold deviation ratio (σ^*/R_{av}) shows promise as shown in Section 2.3. In this case the criterion curve in Figure 9 and the example shown at the end of Section 2.3 can be used as a guide.

D) An upcrossing-rate evaluation method may also be utilized. Again this method requires further evaluation (see Appendix A).

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Appendix A

Review of the Cornell Report on

"An Analytical Method for Determining the Probability Distribution of the Maximum of Combined Responses"

A.1 Introduction

The Cornell Report [10] entitled, "An Analytical Method for Determining the Probability Distribution of the Maximum of Combined Responses" is a study of which the main purpose is to support the Newmark-Kennedy criteria for accepting the square root of sum of the squares (SRSS) rule in combining two or more simultaneously occuring dynamic responses. The two criteria for accepting SRSS rule proposed by Newmark and Kennedy are given in Reference (3). The Cornell report employs an analytical approach, namely the upcrossing method, to construct the nonexceedance probability (NEP) curve of the maximum combined responses based on the random time lag between two component responses. In addition, to the verification of the Newmark-Kennedy criteria, the report also claims that the analytical (up crossing method) approach "can evidently replace the more costly simulation (Monte Carlo) analyses that have been used for this purpose in preceding studies".

The purpose of this review is to carry out a limited evaluation of the validity of the upcrossing method in duplicating the nonexceedance probability curve produced by the Monte Carlo method, and to examine the relative computing cost between the upcrossing method and the Monte Carlo approach. Section A2 is a brief summary of the level upcrossing method suggested in the Cornell report. Section A3 investigates the validity of the Poisson assumption of the distribution of the no crossing of level a, $F_x(a)$. Section A4 investigates the validity of the approximate formula to compute the upcrossing rate $\nu_z(a)$.

Section A5 uses real response time histories to evaluate the NEP of the combined results of two responses by the upcrossing method and the Monte Carlo method presented in the introduction of this report. Section A6 is the conclusion of Appendix A.

A.2 Level Crossing Method

The method using up-crossing rate for computing the probability of exceeding a specified load level has appeared in the recent literature.[10,11] The method is summarized as follows:

Let the random process Z(t) be the sum of two stationary independent random processes $Y_1(t)$ and $Y_2(t)$.

$$Z(t) = Y_1(t) + Y_2(t) \tag{1}$$

where $Y_i(t)$ is the i-th response process with duration T_i and

$$Y_i(t) = A_i X_i(t) \tag{2}$$

in which

$$\max [X_i(t)] = 1$$

$$\max [Y_i(t)] = A_i$$

Assume that the number of upcrossings of the combined process Z(t) to exceed level a in time from 0 to T ($T = T_1 + T_2$) is governed by a Poisson distribution, the probability of no crossing F(a) is known as follows:

$$F(a) = e^{-\lambda T} \tag{3}$$

in which λ is the expected occurrence rate and here it is equal to the mean upcrossing rate ν_a of Z(t). Therefore Equation 3 can be rewritten as

$$F(a) = e^{-\nu_a T} \tag{4}$$

If $\nu_a T \ll 1$ and $e^{-\nu_a T}$ is expanded into power series and retained only the first two terms, Equation 4 becomes

$$F(a) = 1 - \nu_a T \text{ or } 1 - F(a) = \nu_a T \tag{5}$$

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It can be proved that the probability of one or more crossings is bounded by $\nu_a T$.[11] The proof is as follows. The expected number of upcrossings of level a in time from 0 to T is

$$\nu_a T = \sum_{j=1}^{\infty} j \times \Pr \text{ (exactly j crossings)} \tag{6}$$

and the probability of one or more crossings is given by

$$1 - F(a) = \sum_{j=1}^{\infty} \Pr \text{ (exactly j crossings)} \tag{7}$$

Since every term in Equation 6 is an integer multiple of the corresponding term in Equation 7, the Equation 7 is bounded by Equation 6. That is

$$1 - F_z(a) \leq \nu_a T \tag{8}$$

Cornell [11] assumes that if $\nu_a T \ll 1$ then the bound in Equation 8 is sharp and can be used as an approximation. This assumption leads to the same formula as shown in Equation 5 which is derived under Poisson assumption with the condition that $\nu_a T \ll 1$. Cornell[11] also states that the assumption of Poisson arrivals of the upcrossings may give the probability of one or more crossing an even closer approximation, especially at lower values of a.

A.3 Investigation of the Validity of Poisson Assumption

The Poisson distribution is assumed for deriving Equation 4. The assumption is tested twice using the data from Reference 6. From that report (Reference 6), we select two sets of earthquake responses for $Y_1(t)$ (Sets 63, main steam 1I OBE, shroud support OBE) and two sets of SRV responses for $Y_2(t)$ (Sets 32, main steam 1I SRV, shroud support ASRV). Pair 1 represents the random combination of sets 63 and 45 and pair 2 represents the random combination of sets 14 and 32.

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The responses are digitized and are made stationary by following Cornell's procedure.[10] Then we combine the responses by uniformly shifting one with respect to the other with k Δt each time where k is an integer and Δt is the digitizing interval. For the combined response Z(t), the number of crossing of level a from time 0 to T is calculated. The above procedure is repeated for eight different levels, some above and some below SRSS value.

By applying the Pearson χ^2 test to the number of crossings, we can study the goodness of fit for the Poisson assumption. The χ^2-test results are summarized in Tables 1 and 2 and the empirical probability densities for the number of crossings are given in Tables 3 and 4.

By inspecting the results, we have the following observations. In Pair 1, if the level of crossing a is above SRSS, the crossing phenomenon is a rare event (see Table 3, zero-crossing probability), so the Poisson assumption naturally holds. If the level a is at or below SRSS, the Poisson reject the Poisson assumption except at a level near SRSS. In Pair 2, all the indicated levels except the last level at 132, the crossing phenomenon also is a rare event (see Table 4, zero-crossing probability), so the Poisson assumption holds naturally. The χ^2 test strongly rejects the Poisson assumption at level 132, even though the dominant number of crossing is shifted slightly (from zero-crossing to one-crossing).

The actual probabilities of no-crossing and the corresponding value under Poisson assumption with ν_a estimated from the data are shown in Table 5. We can see that the probability of no-crossing is considerably overestimated if the Poisson assumption is rejected by the χ^2 tests.

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A.4 Validity of the Approximate Formula for ν_a

To evaluate Equation 4. Cornell proposed the following approximate formula for computing ν_a (see Reference 10. Equation A4).

$$\nu_a \simeq \int_{-\infty}^{\infty} \nu_{Y_1}(y)\, f_{Y_2}(a-y)\, dy + \int_{-\infty}^{\infty} \nu_{Y_2}(y)\, f_{Y_1}(a-y)\, dy \tag{9}$$

In order to study the validity of the approximation in Equation 9 the responses $Y_1(t)$ and $Y_2(t)$ defined in Figure 1 are considered. Note that $Y_1(t)$ and $Y_2(t)$ are the same in this example. By following the Cornell procedure[11], the responses $Y_1(t)$ and $Y_2(t)$ are modified to be stationary with period $T = T_1 + T_2$. The first term in Equation 9 can be calculated as follows:

$$\int_{-\infty}^{\infty} \nu_{Y_1}(y)\, f_{Y_2}(a-y)\, dy = \int_{-b}^{b} \frac{N}{4Nb} f_{Y_2}(a-y)\, dy = \frac{1}{4b}\left[F_{Y_2}(a+b) - F_{Y_2}(a-b)\right] \tag{10}$$

If we set $a = \sqrt{2}b$ (SRSS value), then $a+b = (\sqrt{2}+1)b$ and $a-b = (\sqrt{2}-1)b$. It is easy to see that

$$F_{Y_2}(a+b) = 1 \tag{11}$$

$$F_{Y_2}(a-b) = \frac{2Nb}{4Nb} + \frac{N(\sqrt{2}-1)b}{4Nb} + \frac{Nb}{4Nb} = \frac{\sqrt{2}+2}{4} \tag{12}$$

where N is number of peaks. Substituting Equations 11 and 12 into Equation 10, then Equation 10 becomes

$$\int_{-\infty}^{\infty} \nu_{Y_1}(y)\, f_{Y_2}(a-y)\, dy = \frac{2-\sqrt{2}}{16b}$$

Similarly, we get

$$\int_{-\infty}^{\infty} \nu_{Y_2}(y)\, f_{Y_1}(a-y)\, dy = \frac{2-\sqrt{2}}{16b}$$

Therefore, the approximate value of ν_a (R-H-S of Equation 9) is

$$\nu_a(\text{approx.}) = 1.172/16b \tag{13}$$

On the other hand, if we randomly shift one response with respect to the other uniformly over the whole duration $T = 4Nb$ as described in Reference 1, we obtain the exact value of ν_a (L-H-S of Equation 9) as follows:

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$$\nu_a \text{ (actual)} = \frac{1}{4Nb}\left\{\frac{b-b/\sqrt{2}}{4Nb}\,[N + 2\,(1 + 2 + \ldots + (N-1))] + \frac{b/\sqrt{2}}{4Nb}\,[N + 2\,(1 + 2 + \ldots + (N-1))]\right\}$$

$$\nu_a \text{ (actual)} = 1/16b \tag{14}$$

The relative difference is

$$\frac{\nu_a \text{ (approx.)} - \nu_a \text{ (actual)}}{\nu_a \text{ (actual)}} = 17\% \tag{15}$$

Since the approximate value of ν_a is larger than the actual value of ν_a in this example, this offers a support that Equation 9 is a conservative approximate formula for ν_a.

However, if we proceed to calculate the probability of no-crossing, F(a), using Equation 4 with approximate and exact value of ν_a in this example, we get

$$[F(a)] \text{ approx.} = e^{-0.293\,N} \tag{16}$$

$$[F(a)] \text{ actual} = e^{-0.25\,N} \tag{17}$$

The relative ratio of F(a) is

$$\alpha = \frac{[F(a)] \text{ approx.}}{[F(a)] \text{ actual}} = \frac{e^{-0.293\,N}}{e^{-0.25\,N}} = (0.95788)^N \tag{18}$$

The ratio α is a function of the number of peaks N (and therefore of T). For example, if N = 10, then α = 0.65. That is the approximate value of F(a) is only about 65% of the true value, even if the ν_a is only overestimated 17%.

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A.5 Comparison of NEP of SRSS of Two Real Responses Based on the BNL Monte Carlo Method and the Upcrossing Method

In order to compare the NEP of SRSS of two real responses based on the BNL Carlo method and the pairs of dynamic response time histories from Reference 6 were selected for combination computation. Table 6 shows the results. For the columns labeled NEP of +SRSS and NEP of -SRSS, upcrossing method results by Cornell [10] and BNL [6] together with Monte Carlo methods by Kennedy [4] and BNL [6] are tabulated. For the column labeled NEP of Abs SRSS only BNL results by upcrossing and Monte Carlo [6] are tabulated since only BNL has computed NEP of Abs SRSS although it is generally recognized that Abs SRSS is the more commonly used definition of the square root of the sum of the squares for the combination of dynamic responses.

In carrying out the upcrossing method, BNL follows the same procedure as presented in Reference 10:

$Z(t) = Y_1(t) + Y_2(t)$

ν_{Y1}^{+}, ν_{Y2}^{+} are the upcrossing rates for the responses $Y_1(t)$ and $Y_2(t)$ at 40 distinct levels

ν_{Y1}^{-}, ν_{Y2}^{-} are the downcrossing rates for the responses $Y_1(t)$ and $Y_2(t)$ are 40 distinct levels

f_{Y1}, f_{Y2} are the marginal probability density function of $Y_1(t)$ and $Y_2(t)$

To model the responses as stationary processes, the following modifications were made

$$\nu_{j,T}(x) = \frac{T_j}{T}\,\nu_{j,T_j}(x)$$

$$f_{j,T}(x) = \frac{T_j}{T}\,f_{j,T_j}(x) + \left(1 - \frac{T_j}{T}\right)\delta(x)$$

where T_j are the durations of the individual responses and $T = \Sigma T_j$.

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The upcrossing rate ν_z^+ (+SRSS) and downing rate ν_z^- (-SRSS) are computed according to Eq. (9) while the crossing rate ν_z (Abs, SRSS) considers both upcrossing and downcrossing of the plus side and minus side of the Abs. SRSS values using the same Eq. (9). Finally the nonexceedance probability of SRSS is

$$F(SRSS) = \exp\{-\nu(SRSS) \cdot T\}$$

By inspection of Table 6, although there are discrepancies between results, the results by the upcrossing method appears to agree well with that by the Monte Carlo method.

A.6 Conclusions

The validities of the assumption of Poisson arrivals of upcrossings and the approximate formula for mean upcrossing rate ν_a are investigated. The Poisson assumption required to derive F(a) in Equation 4 is not necessarily valid unless the process in question is first tested to see if it satisfies the Poisson assumption for the crossing level of interest. Moreover, the use of Poisson assumption without verification leads to an overestimate of the probability of no crossing (see Table 5). In engineering application if we interpret probability of no-crossings as a measure of reliability, this overestimate is not on the safe side.

On the otherhand, the use of conservative approximate formula for ν_a, Equation 9, may lead to a considerable underestimate of the probability of no-crossing under Poisson assumption. It is therefore suspected that the Equation 9 is too conservative to be used in calculation of the probabilities of no-crossings.

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However, when real response combinations are considered, the complete process of evaluating NEP of SRSS based on the upcrossing method appears to be an acceptable approach. On the otherhand, the upcrossing method involves the computation of upcrossing rates and marginal probability density distribution computation of each responses and then the convolution integral to obtain the upcrossing rate of the combined response. Thus, the claim that upcrossing method is less time consuming that the Monte Carlo method when the component responses histories are available is doubtful.

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Table 1

Summary of χ^2 test for Pair 1. Rejection level is determined for 5% significance, D.F. means degree of freedom.

a	χ^2	D.F.	Rejection Level	Conclusion
1120	0.00	1	3.84	accept
1058	0.07	1	3.84	accept
997	5.46	2	5.99	accept
936(SRSS)	22.78	3	7.81	reject
875	3.80	3	7.81	accept
814	82.91	3	7.81	reject
752	230.61	3	7.81	reject
691	782.37	3	7.81	reject

Table 2

Summary of χ^2 test for Pair 2. Rejection level is determined for 5% significance, D.F. means degree of freedom.

a	χ^2	D.F.	Rejection Level	Conclusion
197	0.00	1	3.84	accept
189	0.00	1	3.84	accept
181	0.00	1	3.84	accept
173(SRSS)	0.00	1	3.84	accept
164	0.00	1	3.84	accept
156	0.01	1	3.84	accept
148	0.04	1	3.84	accept
140	0.78	2	5.99	accept
132	1909.66	3	7.81	reject

Table 3

Empirical Probability Densitites for the Number of Crossings at Various Levels for Pair 1.

Level a	0	1	2	3	4
1058	.950	.050			
936(SRSS)	.772	.178	.036	.013	
814	.128	.497	.300	.075	0
691	.0	.033	.176	.761	.031

Table 4

Empirical Probability Densities for the Number of Crossings at Various Levels for Pair 2

Level a	Number of Crossings				
	0	1	2	3	4
189	1.0	0			
173(SRSS)	.999	.001			
156	.982	.018	0	0	
140	.949	.048	.002	0	
132	.016	.934	.042	.008	

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Table 5

Probability of no crossing, F(a)

Level	Pair	[F(a)] actual*	[F(a)] Poisson**
814	1	0.128	0.267
691	1	0	0.061
156	2	.982	.982
140	2	.949	.949
132	2	.016	.353

*[F(a)] actual is the probability of no crossing computed from the data.

**[F(a)] poisson is the probability of no crossing under Poisson assumption with ν_a estimated using the distribution of actual crossings.

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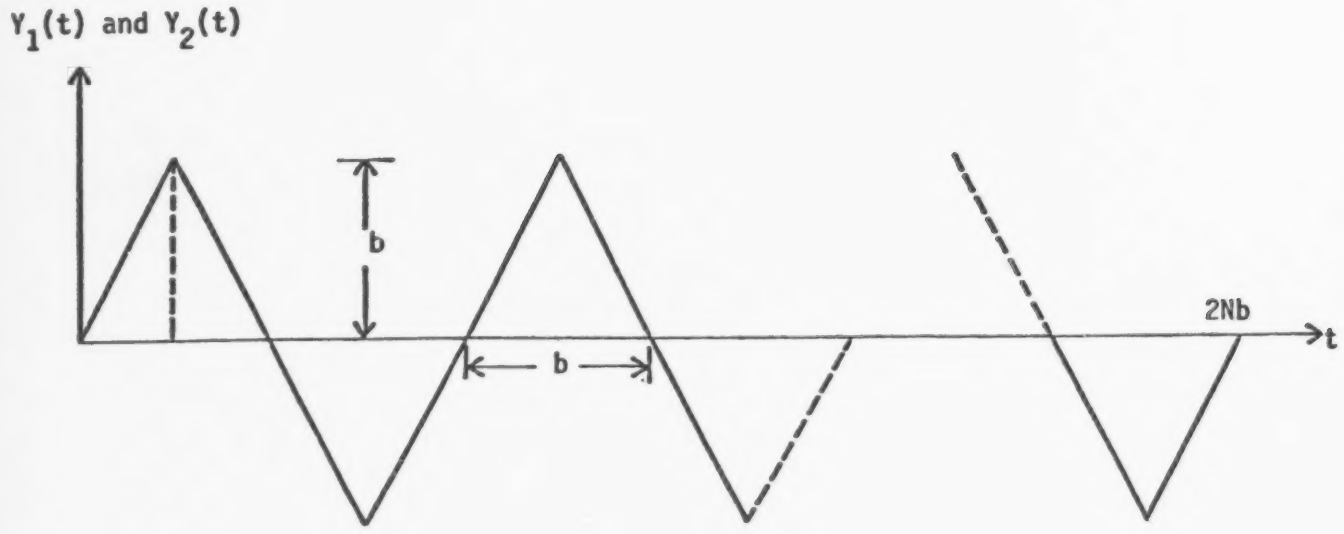

Figure 1. Periodic Triangular Responses

(N is no. of cycles, $T_1 = T_2 = 2Nb$)

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TABLE 6. COMPARISON OF UPCROSSING RATE METHOD AND MONTE CARLO SIMULATION (BNL USES 40 LEVELS IN THE CONVOLUTION INTEGRAL)

RESPONSE COMB.	NEP OF +SRSS				NEP OF −SRSS				NEP OF ABS. SRSS	
	UP CROSSING		MONTE CARLO		UP CROSSING		MONTE CARLO		UP CROSSING	MONTE CARLO
	CORNELL	BNL	KENNEDY	BNL	CORNELL	BNL	KENNEDY	BNL	BNL	BNL
NO. 69 AND NO. 57	0.38	0.39	.46	.43	.51	.61	.58	.59	.37	.51
NO. 71 AND NO. 61	.59	.64	.62	.61	.54	.54	.58	.60		
NO. 42 AND NO. 37	.53	.72	.60	.54	.66	.71	.74	.77	.72	.64
NO. 42 AND NO. 36									.76	.60
NO. 63 AND NO. 45									.84	.68
NO. 63 AND NO. 46									.89	.86
NO. 66 AND NO. 51									.63	.87
NO. 66 AND NO. 52									.65	.79
NO. 69 AND NO. 58									.74	.54

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Appendix B

Suggested Alternate To

Newmark/Kennedy Criterion 1 For

Generic Application

by

R. P. Kennedy

Dynamic or transient responses of structures, components, and equipment arising from combinations of dynamic loading or motions may be combined by SRSS provided that each of the dynamic inputs or responses has characteristics similar to those of earthquake ground motions, and that the individual component inputs can be considered to be relatively uncorrelated. This similarity involves a limited number of peaks of force or acceleration, with approximately zero mean.

The requirement of relatively uncorrelated inputs is met if either of the following is satisfied:

1. The individual dynamic inputs or responses are from independent events so that their relative start times are random.

2. If the relative start times are known, then the coefficient of correlation must be less than 0.4.

The requirement of approximately a zero mean is satisfied if, for the duration of strong input (or response), the ratio of the mean to maximum input (or response) is less than 0.20. If this requirement is not met, responses can be divided into two parts (non-zero mean part, and peak response relative to mean response). The non-zero mean part of response can be combined algebraically (accounting for the sign of the mean response) and the peak

responses relative to the mean responses can be combined SRSS if these relative responses meet the provisions of this criterion.

The requirement of a limited number of peaks is satisfied if any one of the following are met:

1. For each response time history in the combination:

$$\frac{T_{75}}{\Delta T} \leq 0.02$$

and

$$\frac{T_{50}}{\Delta T} \leq 0.08$$

where T_{75} represents the summation of time intervals for all peaks over which the response exceeds 75% of the absolute maximum response, T_{50} represents the time over which the response exceeds 50% of the absolute maximum response, and ΔT represents the relative time interval over which maximum response might be encountered. For the case of random relative start times, ΔT represents the time interval over which these relative start times may occur (generally taken as the duration of strong response of the longer time history). In determining the time T_{75} and T_{50} only the duration of peaks with the same sign (positive or negative) are additive. These definitions are illustrated in Figure 1.

2. For each input-time history in the combination:

$$\frac{T_{75}}{\Delta T} \leq 0.01$$

and

$$\frac{T_{50}}{\Delta T} \leq 0.04$$

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where the definitions are the same as above except with the substitution of input for response. These lesser time ratios for input than for response are chosen in recognition that the response will have more near-peak excursions than the input.

3. If the applicable item 1 or 2 above are not met by each of the inputs or resonses in the combination, this requirement is still satisfied if the effective time ratios $(T_{75}/\Delta T)_e$ and $(T_{50}/\Delta T)_e$ for the response combination meet the requirements of item 1. The effective time ratios for the response combination are given by:

$$\left(\frac{T_{75}}{\Delta T}\right)_e = \sqrt{\frac{\sum_{i=1}^{N}\left(R_m T_{75}/\Delta T\right)_i^2}{\sum_{i=1}^{N}\left(R_m\right)_i^2}}$$

where i represent each individual response in the combination and $(R_m)_i$ represents the maximum response of that response component. The effective time ratio $(T_{50}/\Delta T)_e$ is obtained by substituting 50 for 75 in the above equation.

NOTE: Earthquake input and reponse time histories automatically satisfy the requirements of the characteristics similar to earthquake motion.

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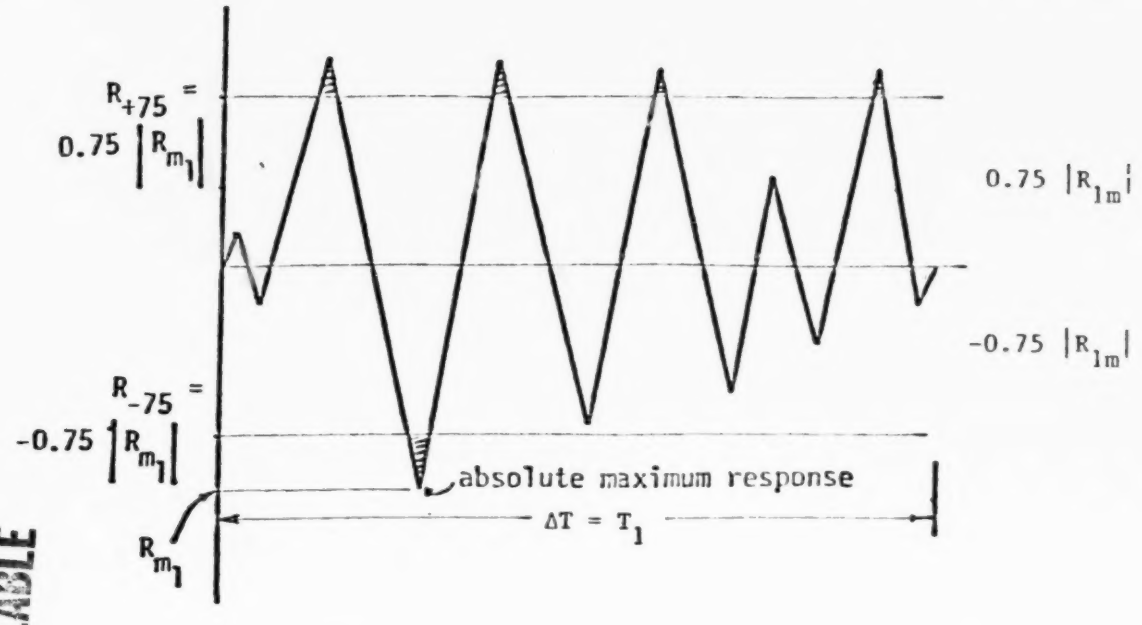
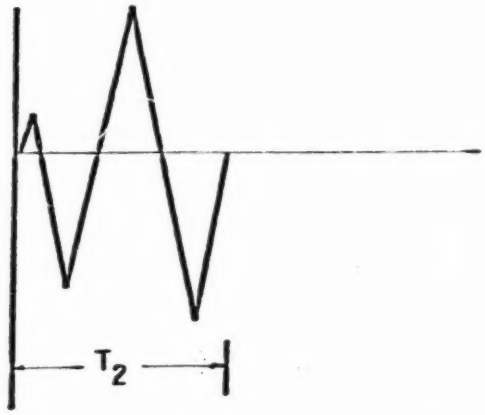


T_{+75} = $\sum$ time that response exceeds R_{+75}

T_{-75} = $\sum$ time that response less than R_{-75}

T_{75} = $\sum$ larger of T_{+75} or T_{-75}



$\underline{T_1 \geq T_2}$; $\Delta T = T_1$

FIGURE 1: Definition of Notation

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This report deals with the problem of combining two or more concurrent responses which were induced by dynamic loads acting on nuclear power plant structures. Specifically, the acceptability of using the SRSS (square root of the sum of the squares) value of peak values as the combined response is investigated. Emphasis is placed on the establishment of a simplified criterion that is convenient and relatively easy to use by design engineers.

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